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New York City Remote Sensing Demonstration Study

Conducted by the Air Quality Laboratory,
Georgia Institute of Technology
In Cooperation with Remote Sensing Technologies, Inc.

May 14 through June 18, 1998

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

FILE ATTACHMENTS

Glossary

AQL	Air Quality Laboratory
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EPA	*ENVIRONMENTAL PROTECTION AGENCY*
GIT	*GEORGIA INSTITUTE OF TECHNOLOGY*
HC	Hydrocarbons (typical formula, C_nH_{2n+2}, but also C_nH_{2n}, and C_nH_{2n-2})
I/M	Inventory and Maintenance
IR	Infrared
NDIR	Non-Dispersive Infrared Spectroscopy
NO_x	Nitric Oxides
NYCDEP	New York City, Department of Environmental Protection
PPM	Parts Per Million (also PPM)
RSD	Remote Sensing Device
RSTi	Remote Sensing Technologies, Incorporated
SDM	Source Detector Module
RDB	Registration Database
RPM	Revolutions per minute
VIN	Vehicle Identification Number
VOC	Volatile Organic Compounds (hydrocarbons and carbonyl carbons, which are double bonded to oxygen)

1. EXECUTIVE SUMMARY

A remote sensing study of motorized vehicular emissions was conducted in the spring of 1998, on vehicles entering and exiting Manhattan's central business district. The New York City Department of Environmental Protection (NYCDEP) sponsored the study. Remote Sensing Technology Inc. (RSTi) was awarded a contract and Air Quality Laboratory of Georgia Institute of Technology (GIT) was selected as primary contractor for data collection and analysis. RSTi provided the equipment and some personnel. While the study was of obvious value locally to NYCDEP, it was also valuable from a more comprehensive perspective. Manhattan fleet is a unique object for the study of auto emissions, because of Manhattan's limited territory, high density of slow moving vehicles, non-stop traffic flow throughout the day with limited choice of access.

The purpose of the study was to evaluate the emissions of vehicles entering and exiting various Manhattan boundary locations (bridges and tunnels) and to determine the influence of different vehicular emissions, by model, type, and state registration, upon New York's air quality. The rationale for the study was to determine the feasibility of integrating remote sensing devices (RSD) into the current New York Inspection and Maintenance (I/M) program and to identify the emissions profiles of commuting vehicles.

At each data collection site, a research van was stationed, which used non-dispersive infrared (NDIR) spectroscopy to measure certain components of vehicle's exhaust. The spectrometer unit, called Source Detector Module (SDM), was positioned near the van and on the same side of a single lane of traffic, as the van. The SDM sent collinear and coaxial infrared (IR) and ultraviolet beams of light across the traffic lane and through the vehicle's exhaust plume, approximately 13-14 inches (0.33 to 0.36 m) above the surface of the road. Then, the beam was reflected back to the SDM's optical system, from a mirror positioned opposite the SDM, on the other side of the traffic lane. (Because the beam was invisible, it did not interrupt traffic flow.) The reflected light was then spectroscopically analyzed for carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC), and nitric oxides (NO_x), each of which have different characteristic absorption spectra.

Spectrographic measurements were made twice for each vehicle, once immediately before the vehicle interrupted the IR beam, to collect background data, and once as the vehicle's exhaust passed through the beam. Additionally, non-exhaust related data were also collected, such as the vehicle's speed, acceleration, and a video image of the license plate for later processing. The license plates were processed through the state vehicle registration database (RDB) and I/M database for social, economic, and other demographic information and analysis related to vehicle model, age, and type.

The RSD technology has many benefits, including the fact that it can collect data on up to 15,000 vehicles, per site, during one day's traffic flow cycle, including morning and evening rush hours. Also, it is much faster, cheaper and less time consuming then standard technology which uses a dynamometer-based test of an engine performance from a no-load idle to increased engine RPM based upon the vehicle's load expectation. Multiple RSD measurements of the same vehicle under different conditions can produce comprehensive information similar to one produced by dynamometer test. Finally, the RSD can be useful for statistical purposes because of the sheer volume of measurements, with minimal expenses.

The New York City study had twenty-nine sampling van-days, at twenty-two different locations on Manhattan, Brooklyn and Queens, mostly on entrances/exits to/from bridges and tunnels. Of the 169,872 vehicles that triggered the RSD system at 22 sites, 117,371 had readable license plates (98,460 from New York and 18,911 from other states, including 15,523 from New Jersey and 408 from Connecticut). Further, 55185 vehicles were identified within the NY registration database.
It was found that overall the taxi cabs are cleaner from an emissions perspective, than the passenger cars or the commercial vehicles. The reason may be, in part, because of a regular strict I/M program for taxis; however, taxis are not as clean as "livery" vehicles recorded in the New York registration database. In its turn, passenger vehicles are cleaner then commercial ones. It is interesting to note that fleet of vehicles from other states in average is cleaner then New York fleet: for CO emissions at about 28%, HC emissions at about 16%, and NOx emissions at about 26%.

2. INTRODUCTION

Between 14 May and 18 June 1998, the Air Quality Laboratory (AQL) from Georgia Institute of Technology (GIT), in cooperation with Remote Sensing Technology Inc. (RSTi), conducted a study of vehicle emissions in New York City, for the New York City Department of Environmental Protection (NYCDEP). The purpose of the study was to determinate the feasibility of using remote sensing technology, to analyze the pollution contribution made by different types of vehicles on New York City streets. The study correlated vehicle emissions to the registration database and VIN (Vehicle Identification Number) decoder information, to have additional information about vehicle and engine design.

To collect emissions data at each site, a research van was parked along a single traffic lane, so that a Source Detector Module (SDM, about the size of a two-drawer filing cabinet) could be positioned to shine an infrared (IR) beam across the lane to a mirror. The SDM and mirror were placed, so that the IR beam was approximately 13 to 14 inches (0.33-0.36m) above the roadway, and passed through the exhaust gases emitted from autos and small trucks, to be reflected back to the SDM optical sensors. Additionally, a video camera was placed so that it recorded the license plate of each vehicle as it passed through the SDM beam. The video and SDM were connected to computer and monitors in the van, where researchers surveyed the data.
The SDM was actually a six channel (CO2, CO, HC, reference_1 - in infrared region and NO, reference_2 – in ultraviolet region) a non-dispersive spectrometer, which analyzed the emissions plume for gaseous products from the combustion of gasoline. Those particular gases were the products of the chemical combustion of fuel in the engine, as seen in the following simplified model reaction of combustion:

$$C_nH_{2n} + O_2 + N_2 ==> CO + CO_2 + C_nH_{2m+2} + NO_x$$

Here n = 7 - 8 correspond to approximated chemical formula of gasoline, m= 3 - 5 describes low order hydrocarbons produced together with carbon monoxide and nitrogen oxides a result of inefficient engine combustion. Remote sensing does not produce direct measurement of actual exhaust plume gas concentrations but they can be calculated if ratios between CO and CO_2, HC and CO_2, and NO_x and CO_2, are known. These ratios are actual variables measured by remote sensing.

Ideal complete combustion of a gasoline produces carbon dioxide and water (CO_2 + H_2O). However, inefficient engine combustion produces excess CO and volatile organic compounds (VOC), which are greenhouse gases, and contributors to photochemical smog. Nitrogen oxides are also produced in combustion reactions, where air is present, and they too are contributors to the production of ozone and photochemical smog. The NO_x chemical species refers to the mixture of NO to NO_2 (for combustion of gasoline NO2 concentration is much lowers then NO concentration). Then in the presence of VOC's, NO_x production of ozone will increase significantly, in a non-linear fashion.

Each of the measured compounds, which were found in the vehicle's exhaust plume, absorbed light from the infrared spectrum in a unique manner, characteristic of the bond structures of that molecule. Each compound's absorption spectrum, measured by the NDIR spectrometer, was a unique "fingerprint" of that molecule, which, in turn, was recorded, both qualitatively and quantitatively (through the ratios).

The technology system of the NDIR, with the SMD, is referred to, as a remote sensing devise (RSD), which allowed for rapid, efficient, and effective monitoring of large numbers of vehicular exhausts. The RSD has no equivalent in traditional technology, where typical engine exhaust gases are measured in a time-consuming manner, one vehicle at a time in a special cycle on dynamometer. Results from RSDs have been proven to be statistically correlated to dynamometer measurements. Precision was also improved by taking two readings for each vehicle. The first was made immediately before the vehicle broke the beam, to provide a background of gases present ahead of the exhaust plume; the second was made immediately after the IR beam was broken, to measure the actual engine emissions. The whole process takes approximately 0.5 seconds. Because of the single lane of traffic, and the rapid recovery of the equipment, as many as 15,000 vehicles were measured in a single day. The system is portable to almost any traffic locations, allowing researchers to collect "live" on-road data, unlike the more traditional equipment.

The video record of the license plate of the vehicle was correlated to the emissions data. The plate numbers provided information about the vehicle and general socioeconomic information about the owner, based upon census data, from the state's vehicle registration database. Besides the vehicle's year, make, and model information, inspection and maintenance data were also available, for certain vehicles. These data allowed for more comprehensive analyses of emissions gases. For example, the vehicle's age, condition, census district, or velocity (which was also recorded at the observation site) could have reported emission levels.

The data entry of license plates into the data files was made manually by GIT personal, during a period between 17 May 1998 and 15 July 1998. The list of valid license plates (those readable from the videos) had been passed to New York City authorities on 16 July 1998, where the list was merged with registration data and returned to GIT by 23 October 1998. Data analysis began after merging the vehicles' emission data with registration data in October 1998 and was finished in February 1999. The results of the analysis are presented in the Summary and Conclusion Section of this Report.

3. SITE SELECTION

Selecting data collection sites was a time consuming task, which required coordination with each agency involved and permission from the New York Police Department (which provided valid working permits to operate at those sites). GIT and RSTi made site selections and preparations in March and April of 1998. Besides the safety of researchers, motorists, and equipment, there were space requirements, and traffic flow expectations. Table 1 explicates the criteria and the weighting scale used to determine optimal research sites.

Table 1 Criteria for site selection, with weighting matrix

Criteria	Weighting	Scores
Site Location Characteristics		
Traffic Volume	2	1-5
Vehicle Type Mix	1	1-2
Diurnal Pattern	--	A-P
Mode of Operation	1	1-3
Physical Site Characteristics		
Single Lane	--	Y-N
Set-up Space	1	1-3
Safety	1	1-3
Calibration Breaks	2	1-5
Grade	1	1-3

The Site Location Criteria were concerned with overall research expectations of maximum traffic flow throughout the day, with good representation of the vehicles of various types belonging to different strata of population. The Physical Site Criteria were used to address the particulars of equipment setup and space for quality data collection.

While not every site selected met every criterion, attempts were made to maximize the effectiveness of each in the overall site selection. Twenty-four sites were finally selected, ten of which were outbound from Manhattan, and fourteen were inbound to Manhattan. Most sites were located in Manhattan and some sites were limited to periods of reduced traffic congestion (beginning between 10 or 11 A.M. and ending between 3 to 5 P.M.). Two sites were problematic: Site 17 was not issued a valid permit and the permit for Site 8 was amended and finally suspended. All other sites, however were approved for study, and proved reliable for remote sensing.

Table 2 lists the sites by specific location, indicating the relative score of each from the criteria weighting indicated in Table 1. The last letter in the site abbreviation represents either Inbound (I) or Outbound (O) traffic lanes. The actual scoring of the sites is shown in Attachment 1.

Table 2 Remote sensing sites

Site Number	Total Relative Score	Abbreviation	Site Address
1A	23	BBMO	Brooklyn Bridge Manhattan Outbound: Entry to Brooklyn Bridge from FDR Drive.
1B	24	BBMO	Brooklyn Bridge Manhattan Outbound: Entry to Brooklyn Bridge from Park Row.
1C	24	BBMO	Brooklyn Bridge Manhattan Outbound: Entry to Brooklyn Bridge from Center Street.
2	22	BBMI	Brooklyn Bridge Manhattan Inbound: Off Ramp to FDR Drive and Pearl Street.
3	26	MBMO	Manhattan Bridge Manhattan Outbound: On-ramp to Lower Level Passing Under Arch. Was coned to single lane by DOT in PM.
4A	23	MBBI	Manhattan Bridge Brooklyn Inbound: Manhattan Bridge exit (#29A) from BQE to Upper Deck.
4B	27	MBBI	Manhattan Bridge Brooklyn Inbound: From Flatbush Avenue to Upper Deck. Merges with Site 4A on-ramp.
5	22	WBBI	Williamsburg Bridge Brooklyn Inbound: Center of Three Merging On-ramps to Bridge. Origin currently unknown.
6	21	WBBO	Williamsburg Bridge Brooklyn Outbound: Off-ramp to BQE East from Upper Deck.
7	30	WBMO	Williamsburg Bridge Manhattan Outbound: From Delancy Street to Upper Deck. BQE eastbound traffic passes site 6.
8	23	MTMI	Midtown Tunnel Manhattan Inbound: Tunnel Exit.
9A	27	QBQI	Queensboro Bridge Queens Inbound: On-ramp to Upper Deck from 21st Street and Queens Plaza North.
9B	27	QBQI	Queensboro Bridge Queens Inbound: On-ramp to Upper Deck from Streets Currently Unknown.
10	24	QBMO	Queensboro Bridge Manhattan Outbound: From 2nd Avenue to Upper Deck.
11	24	QBMO	Queensboro Bridge Manhattan Outbound: From 59th Street to Lower Deck.
12	28	GCTMI	Grand Central Terminal Manhattan Inbound: From Upper Deck of Park Avenue to Park Avenue Southbound.
13	27	CPWMO	Central Park West Manhattan Outbound: Uptown Traffic Crossing 62nd Street on Central Park West.
14	24	WSHMI	West Side Highway Manhattan Inbound: From WSH Southbound to 57th Street via 12th Avenue.
15A	28	LTMI	Lincoln Tunnel Manhattan Inbound: Left Lane Exit from Tunnel.
15B	28	LTMI	Lincoln Tunnel Manhattan Inbound: Right Lane Exit from Tunnel.
16	22	LTMO	Lincoln Tunnel Manhattan Outbound: Single Lane Entrance to Tunnel from 40th and 11th.
17	22	HTMI	Holland Tunnel Manhattan Inbound: Inbound traffic from Tunnel to Downtown and Canal Street.
18	22	BBTMI	Brooklyn Battery Tunnel Manhattan Inbound: At Exit from Tunnel.
21		LMMI	Lower Manhattan Inbound: Intersection of Broadway and 5th Av. Southbound

4. DATA COLLECTION

Two RSD units were used during the data collection period—unit 407 RSD2000 belonging to RSTi and unit 418 RSD2000 belonging to EPA. Both units were tested initially by RSTi, and then by the GIT and RSTi team during the period of the study, at an Envirotest facility at Hartford, CN. Only one unit was deployed during the first week of the study (May 14-21), and during the days of June 6, 11, 16, and 19. Otherwise, both units were used.

During the twenty-nine day data collection period, 169,972 vehicles triggered the RSD, and 117,371 had readable license plates with valid CO samplings (see Table 3). Of the readable plates, 98,460 vehicles were registered in the State of New York, 15,523 vehicles were from New Jersey, and 3388 vehicles were from other states. Repeat observations of same vehicles accounted for 28,486 of the readable license triggers, with some vehicles captured up to eleven times - thus, 11,948 individual vehicles were duplicated one or more times. The raw vehicle data are reported by day, site, and unit number in Attachment 2, while Attachment 3 presents statistics on emission gases, divided by workday and site. All data were transferred successfully to GIT for processing.

Table 3 Analysis of the number of vehicles triggering RSD (beam blocks)

	Beam Blocks	Readable License Plates, (valid readings)	Readable % to Beam Blocks	NY Readable Plates	% to Readable	Other States	% to Readable	Merged with Database	% to Readable NY State
Totals	169972	117371	69.05%	98460	83.89%	18909	16.11%	55185	56%

There were 15,973 vehicles (including repeats) identified as taxi cabs, with only 2259 unique license plates identified from the registration data base. About 75% of Taxis' license plates were not matched with the registration database, and of the 2259 unique cabs, there were 1092 taxis which were duplicated up to seven times in the data set. The following tables provide a breakdown of vehicle types by NY registration database and by VIN decoder.

Table 4 Types of vehicle according to registration database

Vehicle Type	Count of Vehicles	Group	Vehicle Type	Count of Vehicles	Group
AMBULANCE	34	Passenger	OMNIBUS	74	Commercial
BASEBALL	1	Passenger	ORGANIZ	13	Commercial
BOAT	2	Commercial	PASSENGER	39355	Passenger
COMMERCIAL	4750	Commercial	PURPLE HRT	30	Passenger
FRAN. BUS	63	Commercial	REGIONAL	9	Passenger
HAM OPER	6	Passenger	SCHOOL CAR	177	Passenger
HIST MCY	1	Passenger	SEMI-TRLR	1	
HISTORICAL	3	Passenger	SP OFFCIAL	3	Passenger

HORSE COACH	4	Passenger	SP OMNIBUS	561	Commercial
IRP	3	Passenger	SPEC COMMERCIAL	2	Commercial
LIM MC B	1	Passenger	SPEC PASSENGER	810	Passenger
LIM MC C	1	Passenger	SPORTS	17	Passenger
LIVERY	595	Passenger	SPORTS COM	6	Passenger
LT TRLR	2		STATE	1	Passenger
MARINE CRP	16	Commercial	TAXI	2259	Passenger
MED DOCTOR	141	Passenger	TRAILER	2	
MOTORCYCLE	17		VAN POOL	1	Passenger
OFFICIAL	30	Passenger	WRLD GAMES	3	Passenger

Table 5 Type of passenger vehicles according to VIN decoder

VIN decoder TYPE	Count of vehicles
BUS	443
CAR	33264
INC	428
MPV	6229
TRK	1443
VAN	1469

Data were recorded on a single CD-ROM (tagged in accordance with internal standards of GIT's Air Quality Laboratory). The CD-ROM was sent to NYCDEP in MS Word and Excel formats (with file extensions ".doc", ".xls" respectively), as well as in ASCII text (with file extension ".txt"). The list of files and contents follow in Table 6 and the various codes employed are found in Attachment 4.

Table 6 CD-ROM data files and descriptions

1. NYC_98_ReadMe.doc – Present file (ASCII TXT and MS WORD 97)
2. NYC_98_History.doc – Short description of the project, explanation of origin of this release (MS WORD 97)
3. NYC_98_Project.xls – List of sites, results of data collection and data entry (MS EXCEL)
4. NYC_98_Rel8_1DataDict.doc – Explanation of meaning of fields used in the main data base file (MS WORD 97)
5. NYC_98_DataBase – The main data file, contains remote sensing records matched to vehicle registration information and interpreted by VIN decoder (MS ACCESS 97)
6. RSTiNY98Totalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Total Valid Data Collected in New York. (MS EXCEL)
7. RSTINY98NYTotalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Valid Data of New York State licensed vehicles Collected in New York. (MS EXCEL)
8. RSTINY98NotNYTotalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Valid Data of Not New York State licensed vehicles Collected in New York. (MS EXCEL)

The file NYC_98_DataDict.doc, provided on the CD-ROM, has field descriptions and formats explained in Attachment 4.

5. DATA ANALYSIS

Chemical emission data collected for each vehicle included the three ratios CO, HC, and NO_x each to CO_2. From those ratios the amounts of each gas present were determined. The following tables present the statistical analyses of the volumetric percentage of CO (%), and the parts per million (PPM) of HC and NO_x found in the plume. The statistical data are divided by state (New York and non-New York), and by vehicle type, in accordance to the request by NYCDEP, with additional materials provided in the CD-ROM, as defined in Attachment 4.

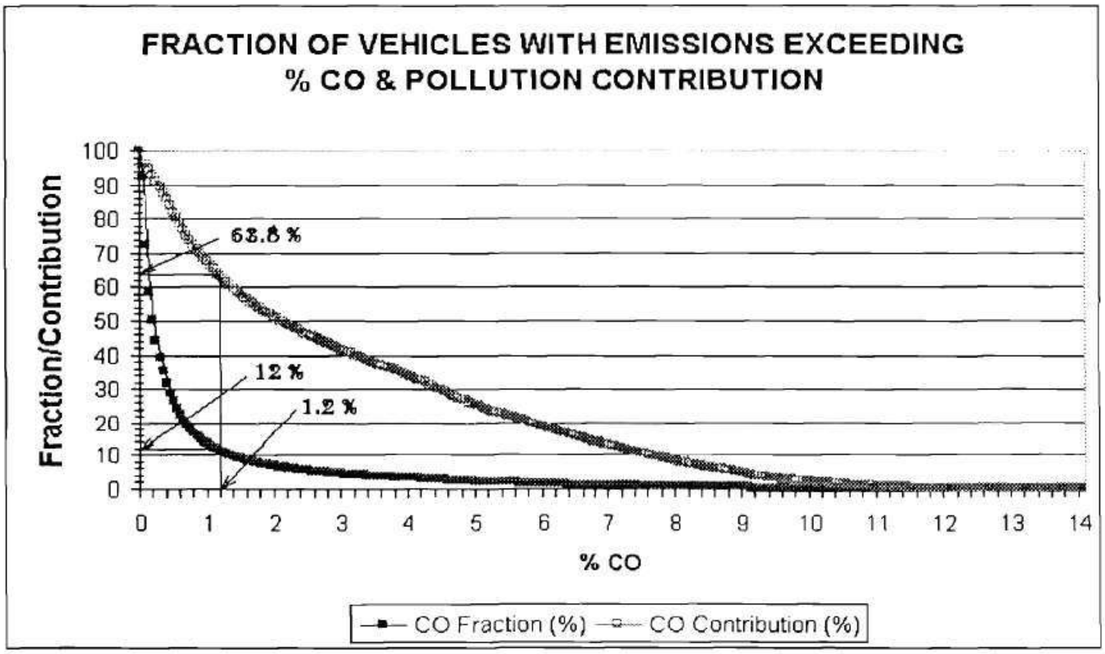
Histograms of frequency distribution have been produced for several populations of vehicles in accordance to the request of NYCDEP. The list of distributions with corresponding file names and pages in Attachment is presented in **File Attachments** table, page 6.

Each Excel file has two worksheets: the first one contains actual emissions data for Histogram and for Descriptive Statistics (it has the same name as the file), the second (named "Charts") has Histogram Charts and Descriptive Statistics tables. The "Charts" sheet consists of six graphs and one table, they may be previewed as four pages. First three contain histograms of CO emissions, HC emissions, and NOx emissions respectively. The last page represents descriptive statistics table. The first chart on each page shows frequency distribution for corresponding emission component. The second chart (See Figure 1) shows cumulative fraction of vehicles with emissions exceeding given value (cumulative function starts from the maximum value) and its contribution to integral emissions of this component.

This figure shows the accumulative fraction of vehicles that contribute to the total pollution from this population of vehicles. The total fraction of pollution is found on the vertical axis, along with the percentage contribution of the vehicles. At the top, one finds 100 % of the vehicles and 100 % of the CO pollution in the atmosphere from this population of vehicular emissions. Along the horizontal axis is the percent of CO found in the exhaust plume. The data can be read as follows: 12 % of the vehicles (from the vertical axis) are exceeding emission levels of 1.2 % of CO (move from the 12% to the lower curve, then down to the axis). At the same time, those vehicles contribute to 63.8% of the total atmospheric pollution from the traffic measured. This value can be found by using the upper curve, and tracing 1.2 % upward from the horizontal axis, to the curve, then moving left to the total percent of pollutants. Conversely, one can see that 88 % of vehicles have CO emission of less than 1.2%, only contributing 36.2 % of total pollution from this population

The data indicate that some few vehicles are high polluters, while most vehicles contribute very little to the total percentage of pollution.

Figure 1. Cumulative fraction of vehicles and their contribution to total CO emissions



We made also comparison of statistics for all valid data obtained in this study and unique identified vehicles, which are part of valid. Unique identified means: only vehicles with readable license plate have been selected and each vehicle is present only once, i.e. repeat observations are averaged. Actually, this is a part of sample available for analysis. Statistics are very close, so we can suppose that conclusions, which we made, are applicable for the whole sample.

General Statistics.

As can be seen from Tables 7 and 8 by the state analysis, New York vehicles have a higher mean value for pollution emission, than out-of state vehicles. They also have a greater spectrum of polluters, with a standard deviation of 1.14, over the standard deviation of 0.96, for non-New York vehicles.

Table 7 Emissions statistics for New York registered vehicles

Descriptive Statistics	CO	HC	NO_x
Mean	0.5146	100.87	686.12
Standard Error	0.0037	0.57	3.00
Median	0.1400	61	329
Mode	0.0200	22	12
Sample Variance	1.291899	29277.19	821494.12
Standard Deviation	1.14	171.11	906.36
Maximum	15.50	7883	6995
Minimum	-0.25	-249	-249
Range	15.75	8132	7244
Sum	47642.49	9133622	62612992
Count	92578	90550	91257

Table 8 Emissions statistics for Non-New York registered vehicles

Descriptive Statistics	CO	HC	NO_x
Mean	0.3760	84.83	515.44
Standard Error	0.0062	1.14	5.05
Median	0.0900	55	209
Mode	0.0200	27	51
Sample Variance	0.929964	30911.81	607134.73
Standard Deviation	0.96	175.82	779.19
Maximum	11.66	15995	6998
Minimum	-0.25	-249	-249
Range	11.91	16244	7247
Sum	9095.64	2027127	12264975
Count	24193	23897	23795

The statistics by vehicle types (Tables 9, 10 and 11) show that taxis are the lowest contributors to the pollutants, while commercial vehicles are the highest. The taxis are also the most consistently low, with a standard deviation of 0.76.

Table 9 Emissions statistics for passenger vehicles registered in New York

Descriptive Statistics	CO	HC	NOx
Mean	0.5385	97.90	647.38
Standard Error	0.0057	0.82	4.30
Median	0.1400	57	300
Mode	0.0200	26	12
Sample Variance	1.41830	28609.7	795019.78
Standard Deviation	1.19	169.14	891.64
Maximum	11.85	7883	6887
Minimum	-0.25	-247	-249
Range	12.10	8130	7136
Sum	23416.16	4168336	27800827.94
Count	43485	42576	42943

3.1.1

Table 10 Emissions statistics for commercial vehicles registered in New York

Descriptive Statistics	CO	HC	NOx
Mean	0.6305	127.14	840.07
Standard Error	0.0182	2.95	13.16
Median	0.1300	74	487
Mode	0.0200	36	29
Sample Variance	1.82179	46588.57	927306.73
Standard Deviation	1.35	215.84	962.97
Maximum	11.25	6004	6594
Minimum	-0.25	-231	-249
Range	11.50	6235	6843
Sum	3459.69	680822.7	4498578.47
Count	5487	5355	5355

Table 11 Emissions Statistics for Taxis

Descriptive Statistics	CO	HC	NOx
Mean	0.4256	98.27	616.35
Standard Error	0.0159	2.74	15.35
Median	0.2100	70	361.5
Mode	0.0300	56	34
Sample Variance	0.573380	16838.98	530781.22
Standard Deviation	0.76	129.77	728.55
Maximum	11.33	1796	6259
Minimum	-0.20	-239	-249
Range	11.53	2035	6508
Sum	961.48	219740.2	1388626.379
Count	2259	2236	2253

The analysis of various types of vehicles as compared to average for total fleet (Tables 12 and 13) also shows that taxis are on the low end of pollutants while commercial vehicles are on the high end.

Table 12 Emissions statistics for passenger vehicles: average for groups and percent difference to average of total fleet

	All	Passenger Car	% Differ	Livery	% Differ	Taxi	% Differ	MPV	% Differ
CO	0.5385	0.5448	1.18%	0.3997	-25.78%	0.4256	-20.96%	0.4226	-21.52%
HC	0.019581	0.0195	-0.25%	0.0157	-19.71%	0.0196	0.38%	0.0170	-13.04%
NO_x	0.064739	0.0647	-0.02%	0.0666	2.86%	0.0616	-4.80%	0.0571	-11.65%

Table 13 Emissions statistics for commercial vehicles: average for groups
and percent difference to average of total fleet

	Commercial	Cars	% Difference	Other	% Difference
CO	0.6305	0.4128	-34.53%	0.6917	9.70%
HC	0.025428	0.0165129	-35.06%	0.027218	7.04%
NO_x	0.084007	0.0425068	-49.40%	0.086433	2.89%

These data are confirmed by analysis of degradation of various vehicle types with age: Figures 2 to 8. As we can see from these graphs old commercial vehicles are always "dirtier" then passenger vehicles. For taxis, similar graphs reflect dependence on mileage, because this variable describes better degradation of this type of vehicle then age. It is important to note then even dirtiest taxis have emissions lower or equal to standard allowable limits for idle test: 1.2% CO, 220 PPM HC, and 1200 PPM NOx, while oldest vehicles of other groups exceed these limits.

Fig 2 shows also distribution of vehicles by model year in our sample, it is compared to similar data for Vermont (study in April 98 with the same equipment). This is a typical kind of curve, similar to those observed earlier for Atlanta, Boston, Baltimore and other cities. It reproduces well distribution of vehicles by model year in registration database. On the same graph dependence of CO, average on vehicle age is reproduced. It is interesting to note that comparison New York fleet versus Vermont fleet clearly shows that New York fleet as a total has average CO approximately 20% higher. Possible reason may be higher mileage of New York vehicles, which supposedly commute longer distances. Fleet distribution by model year also shows that the fleet growth in 1987-1991 and 1994-1997 observed for Vermont is not present in New York. The explanation may be specifics of state development during these periods.

High Emitters.

As it was shown in previous studies, one of the main factors determining level of vehicle fleet emissions is increase of average emissions with the vehicle age (Figures 2 to 8). It is determined in its turn by increase of high emitter number. The standard level of emission for describing clean vehicles is defined by the local agency authorizing the vehicular testing, and it is the maximum level of emission allowed by that particular maintenance program. Widely accepted limits are 1.2% CO, 220-PPM HC (by Hexane) and 1250 PPM for NOx. GIT recommends that the level of tolerance for classifying high emitting vehicles be obtained by multiplying these lower levels times three, i.e. vehicle considered definitely "dirty' by remote sensing if it emits more 3.6 % CO, 660 PPM of HC, and 3750 PPM NO_x. We discuss later reasons of these limits for CO.

Figure 9 shows increase of percentage of high emitters, CO>3.6%, with model year and their contribution to total pollution for vehicles of given year. It is important to note that for new vehicles even small amount of high emitters makes relatively high contribution to total pollution. For old vehicles, their contribution is dominant.

On Figure 10, all vehicles are divided into four groups with 5 years age range, and their contributions to total pollution are compared. It confirms the widely anticipated assumption that the main contribution is determined by high emitters among medium age vehicles, 5<=age<=15, which are supposedly not properly maintained. The vehicles older then 15 years, though they are the dirtiest, are small in numbers and their contribution is relatively low.

The major analysis was made for all valid vehicles, then for vehicles with readable license plates that were identified as New York state vehicles, and then for out of state vehicles with the purpose of comparing these two categories. Data for New York State vehicles and out of state vehicles are presented in Table 15 for each site, each day, and each hour. This data show average CO separately for all vehicles and for high emitters.

Figures 11- 13 and Figures 14 – 42 of Attachment 16 show observations of high emitters on various sites. On Figure 11, summarized data are presented for all the sites. We could not use limit of 3.6% for site analysis because there was not enough data for statistics, so we used the limit of 2.4%. Actual percentage of high emitters defined by CO>=3.6% should be lower approximately 35% as follows, however time patterns of high emitters flow are the same (see Figure 11). To avoid errors due to calibration time and any other pauses in RSD operation, average hourly traffic (column "Hour Traffic Avg.") was calculated using known number of vehicles during actual minutes of work for each hour. This number was extrapolated then for the whole hour (it was especially important for early morning hours). The percent of high emitters was calculated in similar way. Two lines shown on chart for each day: one represents percentage of high emitters by hour and second one represents average traffic for this site by hour. The summary charts on Figure 2 shows all New York vehicles by hour versus out of state vehicles. Figure 3 represents high emitter flow for inbound sited versus outbound sites.

It is necessary to note that time patterns of actual traffic flow may differ significantly from the one observed by us. The reason is that we did not have permits to work during rush hours on the sites with highest traffic flow. As can be seen from Fig-s (14 – 44) for majority of sites we did not observe any specific changes during rush hours, also there is no correlation between number of high emitters and total vehicle flow. For many sites, we observed trend to increase of high emitter fraction towards late afternoon.

Analysis of high emitters is represented in Attachment; it was made in Microsoft Excel spreadsheet and saved in file named NY98SummHighEmmit.xls on CDROM together with other files. All data sets were generated by queries in Microsoft Access and then were transferred to Excel.

Repeat observations.

In this study we had several episodes of observation the same vehicle three and more times and many cases of same vehicle appearance two times. Analysis of multiple observations of the same vehicle (repeats) is useful for estimation of remote sensing measurement quality and for estimation of reliability limits for clean vehicles screening and high emitters tracking methodologies. In terms of qualitative chemical analysis, **precision** is a measure of the reproducibility of result; **accuracy** refers to how close a measurement value is to the "true" value. Accuracy of remote sensor as an instrument to measure concentrations of above mentioned gases from their ratios to CO2 was established by manufacturer during certification by means of audit truck that carries cylinders of known concentrations of gaseous pollutants. The audit vehicle releases gases several seconds before truck crosses the beam of RSD, continuing past the RSD, and for a few seconds beyond passage of RSD. Figure 42 shows results of this kind of certification for CO. It is much more difficult to determine accuracy of remote sensor for on-road measurements since it makes a snapshot of vehicle emission during 0.5 second, and vehicle exhaust variability, which depends on many factors, significantly influences measurement result. This variability is always present in spite of our efforts to select best possible site. However, multiple observations of the same vehicle or of the group of similar vehicles should produce results that are more authentic. Figure 43 (T. Wenzel), shows high correlation of remote sensing data and dynamometer IM240 test, averaged for large groups of vehicles of the same model year (the same approach that we used for Figure 2).

In this study, we had 11948 cases of two observations, 3044 cases of 3 observations, 1002 cases of four observations, and 334 cases of 5 to 11 observations.

Figure 44 show that spread of data for multiple observations are relatively high. However histograms and descriptive statistics are very close – see Figure 45. It means that each of four observations produces the same statistical parameters of the sample, though individual readings of each car may differ significantly.

To estimate possible limits of clean screen methodology (cleanest vehicles should be exempt from emission test based on their remote sensing readings), and high emitter tracking methodology (vehicles which are definitely dirty according to remote sensing are subject to mandatory test). We analyzed spread of readings of vehicles with four or more observations in the range of average CO (CO avg.) from 0 to 6.2%. – see Fig 46 and 47. At low concentrations CO<=1% (Figure 46) standard deviation increases linearly with CO increase, at high concentrations CO>=2% (Figure 47) it is almost constant. As we can see from Figure 46 at CO avg. less then 0.3 – 0.4% estimated standard deviation does not exceed 0.4%. It means that in the interval of two standard deviations result of measurement remains lower then 1.2%, i.e. vehicle is supposedly clean. We can come to the opposite conclusion using data of Figure 46: vehicle is supposedly dirty (any CO reading is higher then 1.2%) if CO avg.>=5%. However these estimations are relatively rude, since we do not have sufficient statistical data and distribution of vehicles by CO emissions is far from normal, it is closer to exponential or Gamma-distribution.

To investigate the problem more thoroughly we analyzed data of 10 groups of vehicles with 3 or more observations and average CO equal or close to 0.05, 0.3, 0.4, 0.5, 0.6, 1.0, 1.25, 2.4, 3.6, 5.5%. We selected as preliminary threshold for clean screen 0.3% and for high emitters 3.6%.

For clean screen methodology, when the attempt is made to select without fail definitely clean vehicles, important questions are:

- What percentage of cleanest vehicles (CO avg.<=0.3) will be actually observed and what percentage will be missed (error of omission)
- What percentage of clean vehicles (CO avg.<1.2) will be observed and what percentage will be missed
- What percentage of dirty vehicles (CO avg.>=1.2) may be observed with emissions in the interval CO<=0.3 and wrongly identified as clean (error of commission)

For high emitter selection similar questions are:

- What percentage of high emitters (CO avg.>=3.6) will be actually observed and what percentage will be missed (error of omission)
- What percentage of dirty vehicles (CO>=1.2) will be observed and what percentage will be missed
- What percentage of clean vehicles (CO avg.<1.2) may be observed with emissions in the interval CO>=3.6% and wrongly identified as high emitters (error of commission).

Fig 48 and 49 show corresponding estimations for group of cleanest vehicles with the average CO at high threshold of 0.3% and group of high emitters with the average CO at low threshold of 3.6%. For example, from Figure 49 we can estimate that for vehicles with COavg=3.6% probability of being observed at one appearance as high emitter is 47%, i.e. error of omission for this group is 53%. In total there is 82% probability that it will be registered as dirty vehicle (CO>=1.2%), and there is 2% probability that it will be wrongly identified in the range of clean screen (CO<0.3%). The best way to decrease this most undesirable error is to use criterion of two appearances with CO>=3.6%, if theses are two independent observations (at least different day/site) probability of above mentioned error becomes negligibly small: 0.04%.

Graphs on Figure50 summarize results of similar analysis for all 10 above-mentioned groups. It is important to note that there is a relatively high probability for dirty vehicles (CO>1.2%) to appear in the clean screen range: 25 % at CO=1.2% - see curve 1 and for clean vehicles (CO<1.2%) to appear in the high emitter range: 8% at CO=1.2% - see curve 4. As was mentioned above, the best way to decrease these errors is to use two observations of the same vehicle.

Estimation of total error for all the vehicles can be done if their distribution by CO% is known. We did this kind of estimation for commercial vehicles in New York; their distribution is shown on Figure 51. From graphs on Figure 51 we can conclude that in the clean screen range 71% of clean vehicles (CO<1.2%) will be observed at one appearance and 57% - at two appearances. From graphs Figure 52 we conclude that there is approximately 12% probability for dirty vehicles (CO>1.2%) to have emissions in the range CO<=0.3% (error of commission to clean screen) for one observation and 1.7% for two observations.

6. Summary and Conclusions

During last few years, the remote sensing technology has shown high efficiency for the purposes of fleet evaluation and as a support and additional tool for existing I/M programs. The accuracy of remote sensing dramatically increased and reached the point when it can be used not only for monitoring purposes but also for testing of vehicles by means of special procedures. One of them uses elevated ramp and three remote sensors positioned on entrance part of ramp going upgrade about 5 %m (acceleration under load), middle part with zero grade (uniform speed), and downgrade exit (breaking). Canadian research group has represented this system in March 1996 at Sixth CRC On-Road Vehicle Emissions Workshop. Last year EPA released recommendations for using remote sensing technology for clean screen methodology. This methodology has been tested now by several states. The technology is in the stage of active development and may replace in future some of the testing procedures and become the standard for vehicle fleet evaluation.

Attachment 4: Data Files, and the Codes, Abbreviations, and Descriptions used in files

A CD-ROM was prepared for NYCDEP with a number of files in MS Word and MS Excel formats (with file extensions ".doc", ".xls" respectively), as well as in ASCII text (with file extension ".txt"). The list of files and contents is repeated from the text (Table 6), as Table 1, below.

Table 14 CD-ROM Data files and descriptions

7. NYC_98_ReadMe.doc – Present file (ASCII TXT and MS WORD 97)
8. NYC_98_History.doc – Short description of the project, explanation of origin of this release (MS WORD 97)
9. NYC_98_Project.xls – List of sites, results of data collection and data entry (MS EXCEL)
10. NYC_98_Rel8_1DataDict.doc – Explanation of meaning of fields used in the main data base file (MS WORD 97)
11. NYC_98_DataBase – The main data file, contains remote sensing records matched to vehicle registration information and interpreted by VIN decoder (MS ACCESS 97)
12. RSTiNY98Totalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Total Valid Data Collected in New York. (MS EXCEL)
13. RSTINY98NYTotalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Valid Data of New York State licensed vehicles Collected in New York. (MS EXCEL)
14. RSTINY98NotNYTotalhist.xls – Basic Histogram and Fraction, Contribution Table and Charts for Valid Data of Not New York State licensed vehicles Collected in New York. (MS EXCEL)

Each file contains spreadsheets for the data, including histograms and descriptive statistics, with an appropriate name (e.g., Histogram Charts or Descriptive Statistics). The "Charts" spreadsheets each have four pages, the first three of which present charts for CO emission, HC emission and NO_x emission, in that order. The last page represents the descriptive statistics table. The first chart on each page shows the frequency distribution for each of the emission components.

The following table lists the various abbreviations or codes used in the raw data files, the formats of those data, and a brief description of what that data mean.

Table 15 Data fields, formats, and descriptions

	Field Name	Format	Description
1.	Record_ID	Long Integer	Unique record number in the table
2.	RSDUnitNumber	Integer	RSTi Number of instrument
3.	VehicleSequence	Long Integer	Sequence Vehicle number on the jazz disk
4.	Date	Date, DD/MM/YY	Date of Remote Sensing Measurement
5.	Time	Time, hh:mm:ss	Time of Remote Sensing Measurement
6.	CO	Double	Remote Sensing CO Measurement in %
7.	COFlag	Text	CO measurement validation :V – valid, S – suspect, X – invalid, E –

		insufficient plume, N – data does not exist
8. CO_2	Double	Remote Sensing CO_2 Measurement in %
9. CO_2Flag	Text	CO_2 validation (same as above for CO)
10. MaxCO_2	Double	Maximum of CO_2 concentration in the volume of air covered by IR beam, as related to calibration
11. CO_2Volume	Double	Integrated in time CO_2 concentration in the beam
12. HCppm	Double	Remote Sensing HC Measurement in PPM of Hexane
13. HCFlag	Text	HC validation (same as above)
14. NOxppm	Double	Remote Sensing NOx Measurement in PPM
15. No_xFlag	Text	NO_x validation (same as above)
16. Opacity	Text	Exhaust plume opacity as measured in reference channel
17. OpacityFlag	Text	Opacity validation (same as above)
18. ColdStart	Boolean	Estimation of cold start probability from absorption in H_2O vapor channel, not functioning
19. Speed	Double	Vehicle speed in mph
20. SpeedFlag	Text	Speed validation (same as above)
21. Acceleration	Double	Vehicle acceleration in mph/sec
22. AccelerationFlag	Text	Acceleration validation (same as above)
23. SpeedAcceleration	Text	Units of measurement of Units speed/acceleration, E–means English, see above
24. LicensePlate	Text	License Plate of the vehicle
25. LicensePlateFlag	Text	See below separate paragraph
26. LicensePlateType	Text	See below separate paragraph
27. Odometer	Long Integer	Odometer Reading, if available
28. C/Icode	Text	C/I Code
29. Address	Text	Owner's Address
30. City_State	Text	City and State of Vehicle Registration
31. County	Text	County
32. Zip	Text	ZIP Code
33. VehType	Text	Vehicle Type from NY Registration Data Base (NY RDB)
34. Make	Text	Vehicle Make from NY RDB
35. Color	Text	Vehicle Color
36. Body	Text	Vehicle Body from NY RDB
37. Year	Integer	Vehicle Model Year from NY RDB
38. VIN	Text	Vehicle Identification Number

39. VehWeight	Long Integer	Vehicle Weight from NY RDB
40. Cylinders	Integer	Number of engine cylinders
41. Fuel	Text	Type of fuel
42. ExpirationDate	Date	Validation Test effective by this Date
43. ValidationDate	Date	Emission Test passed Date
44. HCperc	Double	HC concentration in % of Propane
45. NO_xperc	Double	NO_x concentration in %
46. VinYear	Text	Vehicle Year (from VIN)
47. VinMake	Text	Make (from VIN)
48. VinSeries	Text	Model (from VIN)
49. VinBody	Text	Body Style (from VIN)
50. VinDisp	Text	Displacement
51. VinUN	Text	Units of displacement(Liter or Cubic Inch)
52. VinCYL	Text	Number of Cylinders (from VIN)
53. VinASP	Text	Fuel Aspiration
54. VinIND	Text	Fuel Induction
55. VinAIR	Text	Air Injection Reactor System
56. VinEVP	Text	Evaporative Emissions Controls
57. VinOXY	Text	Oxidation (two way) Catalyst
58. VinTWC	Text	Three Way Catalyst
59. VinEGR	Text	Exhaust Gas Recirculation
60. VinCLL	Text	Closed Loop Combustion Control
61. VinPCV	Text	Positive Crankcase Ventilation
62. VinTAC	Text	Thermostatic Air Cleaner
63. VinManuf	Text	Manufacturer (from VIN)
64. VinCntry	Text	Country of Manufacturer (from VIN)
65. VinType	Text	Type of Vehicle (from VIN)
66. VinGVWR	Text	Gross Vehicle Weight Range

The following files are contained on the CD-ROM provided to NYCDEP.

Table 16 Daily High Emitters CO > 2.4% Traffic Flow.

Date	Unit Number	Daily Mean CO	Current Hour	Count Of Veh	Hourly Means	Count High Emitters CO	Hourly Means HE	Hour Traffic Avg.	Percent of HE	Work Time
5/14/98	418	0.4915	6	250	0.5247	14	4.7657	702	5.60	21
5/14/98	418	0.4915	7	746	0.5447	41	4.8563	746	5.50	59
5/14/98	418	0.4915	8	606	0.4104	23	4.5626	606	3.80	59
5/14/98	418	0.4915	9	513	0.4565	24	5.4654	513	4.68	59
5/14/98	418	0.4915	10	623	0.4109	22	4.8818	623	3.53	59
5/14/98	418	0.4915	11	461	0.5203	24	4.7158	461	5.21	59
5/14/98	418	0.4915	12	446	0.3626	14	4.3307	446	3.14	59
5/14/98	418	0.4915	13	409	0.4532	15	5.4587	409	3.67	59
5/14/98	418	0.4915	14	402	0.6699	33	4.9542	402	8.21	59
5/14/98	418	0.4915	15	470	0.5433	28	5.0868	470	5.96	59
5/14/98	418	0.4915	16	455	0.5611	29	4.6262	455	6.37	59
5/14/98	418	0.4915	17	543	0.5268	32	3.9931	543	5.89	59
5/14/98	418	0.4915	18	182	0.3957	7	3.9743	358	3.85	30
5/15/98	418	0.5415	6	172	0.6191	10	6.1210	274	5.81	37
5/15/98	418	0.5415	7	291	0.3400	6	4.3433	291	2.06	59
5/15/98	418	0.5415	8	271	0.5363	16	4.9413	271	5.90	59
5/15/98	418	0.5415	9	180	0.4474	12	4.0625	180	6.67	59
5/15/98	418	0.5415	10	57	0.3296	1	4.0400	210	1.75	16
5/15/98	418	0.5415	11	103	0.5442	6	5.2983	405	5.83	15
5/15/98	418	0.5415	12	398	0.4388	19	4.6858	398	4.77	59

5/15/98	418	0.5415	13	429	0.5615	25	5.3708	429	5.83	59
5/15/98	418	0.5415	14	478	0.5305	26	4.7154	478	5.44	59
5/15/98	418	0.5415	15	456	0.6576	28	5.3646	456	6.14	59
5/15/98	418	0.5415	16	405	0.6502	23	4.8239	405	5.68	59
5/15/98	418	0.5415	17	542	0.6320	29	5.3621	542	5.35	59
5/15/98	418	0.5415	18	629	0.4945	28	4.8846	629	4.45	59
5/16/98	418	0.5586	7	259	0.4609	14	4.3414	1019	5.41	15
5/16/98	418	0.5586	8	976	0.5749	62	5.0889	976	6.35	59
5/16/98	418	0.5586	9	947	0.5372	50	5.3636	947	5.28	59
5/16/98	418	0.5586	10	934	0.4954	47	4.6379	967	5.03	57
5/16/98	418	0.5586	11	963	0.6243	54	5.3098	963	5.61	59
5/16/98	418	0.5586	12	998	0.5903	59	4.8646	998	5.91	59
5/16/98	418	0.5586	13	1006	0.6408	66	5.3203	1006	6.56	59
5/16/98	418	0.5586	14	921	0.5370	52	4.7987	921	5.65	59
5/16/98	418	0.5586	15	911	0.5259	47	4.8230	911	5.16	59
5/16/98	418	0.5586	16	973	0.5352	49	5.7208	973	5.04	59
5/16/98	418	0.5586	17	841	0.5610	44	5.2825	841	5.23	59
5/16/98	418	0.5586	18	481	0.5192	29	4.5228	1014	6.03	28
5/17/98	407	0.2961	8	235	0.2561	3	6.2200	272	1.28	51
5/17/98	407	0.2961	9	337	0.2956	5	3.8520	337	1.48	59
5/17/98	407	0.2961	10	473	0.2676	6	4.4900	473	1.27	59
5/17/98	407	0.2961	11	560	0.2484	4	4.5525	560	0.71	59
5/17/98	407	0.2961	12	620	0.3573	15	4.7173	620	2.42	59
5/17/98	407	0.2961	13	494	0.2744	7	4.7600	494	1.42	59
5/17/98	407	0.2961	14	690	0.2593	14	4.0143	690	2.03	59
5/17/98	407	0.2961	15	558	0.2945	9	4.2911	658	1.61	50

5/17/98	407	0.2961	16	426	0.3938	11	5.1818	661	2.58	38
5/17/98	407	0.2961	17	402	0.3330	8	5.7238	416	1.99	57
5/17/98	407	0.2961	18	286	0.2698	5	3.7040	603	1.75	28
5/18/98	407	0.4351	7	492	0.3787	16	4.9200	518	3.25	56
5/18/98	407	0.4351	8	403	0.2779	9	5.3622	403	2.23	59
5/18/98	407	0.4351	9	423	0.4109	11	6.3245	423	2.60	59
5/18/98	407	0.4351	10	354	0.4811	15	4.7080	464	4.24	45
5/18/98	407	0.4351	11	673	0.3633	19	4.1642	685	2.82	58
5/18/98	407	0.4351	12	551	0.4845	27	4.3678	551	4.90	59
5/18/98	407	0.4351	13	800	0.5224	38	5.0937	800	4.75	59
5/18/98	407	0.4351	14	800	0.4847	30	5.7337	1004	3.75	47
5/18/98	407	0.4351	15	367	0.3730	11	4.4527	425	3.00	51
5/18/98	407	0.4351	16	353	0.4736	14	4.9757	353	3.97	59
5/18/98	407	0.4351	17	243	0.4924	8	4.5325	243	3.29	59
5/18/98	407	0.4351	18	151	0.3820	2	8.4200	223	1.32	40
5/19/98	418	0.5911	6	479	0.5100	18	4.6922	856	3.76	33
5/19/98	418	0.5911	7	974	0.5545	40	4.9428	974	4.11	59
5/19/98	418	0.5911	8	446	0.5556	21	5.2319	1053	4.71	25
5/19/98	418	0.5911	10	283	0.5552	20	4.2685	879	7.07	19
5/19/98	418	0.5911	11	882	0.4474	32	4.4369	882	3.63	59
5/19/98	418	0.5911	12	831	0.6256	49	5.1459	831	5.90	59
5/19/98	418	0.5911	13	828	0.6437	52	5.0913	828	6.28	59
5/19/98	418	0.5911	14	931	0.6553	67	4.2836	931	7.20	59
5/19/98	418	0.5911	15	891	0.6912	67	4.4231	891	7.52	59
5/20/98	418	0.4779	10	292	0.5426	15	5.3327	615	5.14	28
5/20/98	418	0.4779	11	599	0.5274	36	4.6006	599	6.01	59

5/20/98	418	0.4779	12	754	0.5381	47	4.5728	754	6.23	59
5/20/98	418	0.4779	13	731	0.4407	33	4.3355	731	4.51	59
5/20/98	418	0.4779	14	688	0.3801	23	5.0830	688	3.34	59
5/21/98	418	0.4738	7	412	0.4894	16	5.1544	412	3.88	59
5/21/98	418	0.4738	8	480	0.4607	16	4.7050	480	3.33	59
5/21/98	418	0.4738	9	547	0.4284	21	4.2019	547	3.84	59
5/21/98	418	0.4738	10	622	0.5527	29	5.4314	622	4.66	59
5/21/98	418	0.4738	11	589	0.4919	27	4.9904	589	4.58	59
5/21/98	418	0.4738	12	671	0.4381	26	4.5250	671	3.87	59
5/21/98	418	0.4738	13	610	0.4618	25	4.7872	610	4.10	59
5/21/98	418	0.4738	14	575	0.4555	25	4.4656	575	4.35	59
5/21/98	418	0.4738	15	433	0.4896	19	4.5679	433	4.39	59
5/21/98	418	0.4738	16	567	0.5035	29	4.6745	567	5.11	59
5/21/98	418	0.4738	17	659	0.4986	30	4.5210	659	4.55	59
5/21/98	418	0.4738	18	427	0.3710	11	4.1682	763	2.58	33
5/22/98	407	0.6706	10	136	0.5082	5	4.2220	535	3.68	15
5/22/98	407	0.6706	11	335	0.7323	26	5.0615	341	7.76	58
5/22/98	407	0.6706	12	446	0.6150	30	4.9697	446	6.73	59
5/22/98	407	0.6706	13	498	0.6819	41	4.5993	498	8.23	59
5/22/98	407	0.6706	14	546	0.6993	46	4.6000	546	8.42	59
5/22/98	418	0.4938	8	819	0.5196	49	4.6020	1028	5.98	47
5/22/98	418	0.4938	9	892	0.4847	48	4.1171	892	5.38	59
5/22/98	418	0.4938	10	507	0.4658	27	4.2478	507	5.33	59
5/22/98	418	0.4938	11	203	0.4496	8	5.2175	203	3.94	59
5/22/98	418	0.4938	12	261	0.5117	14	5.3600	261	5.36	59
5/22/98	418	0.4938	13	278	0.5117	16	5.0606	278	5.76	59

5/22/98	418	0.4938	14	200	0.5024	12	3.8650	200	6.00	59
5/26/98	407	0.5995	10	28	0.2918			79		21
5/26/98	407	0.5995	11	428	0.5825	23	4.7965	451	5.37	56
5/26/98	407	0.5995	12	340	0.6637	20	5.1745	340	5.88	59
5/26/98	407	0.5995	13	438	0.5880	24	3.9417	438	5.48	59
5/26/98	407	0.5995	14	400	0.5989	22	3.9059	400	5.50	59
5/26/98	418	0.5412	8	304	0.5191	13	4.7638	359	4.28	50
5/26/98	418	0.5412	9	253	0.4959	9	5.3256	253	3.56	59
5/26/98	418	0.5412	10	144	0.6253	8	5.8913	144	5.56	59
5/26/98	418	0.5412	11	153	0.5314	6	5.4883	153	3.92	59
5/26/98	418	0.5412	12	147	0.4056	4	5.2775	150	2.72	58
5/26/98	418	0.5412	13	180	0.5195	9	5.1767	180	5.00	59
5/26/98	418	0.5412	14	211	0.4851	9	4.3700	211	4.27	59
5/26/98	418	0.5412	15	246	0.5992	14	5.1543	246	5.69	59
5/26/98	418	0.5412	16	201	0.7172	16	4.8231	201	7.96	59
5/26/98	418	0.5412	17	256	0.5163	14	4.4943	256	5.47	59
5/27/98	407	0.5635	9	588	0.5904	28	5.4179	1020	4.76	34
5/27/98	407	0.5635	10	363	0.6743	22	5.2100	1127	6.06	19
5/27/98	407	0.5635	13	223	0.5479	13	5.4046	356	5.83	37
5/27/98	407	0.5635	14	498	0.4520	22	4.5686	498	4.42	59
5/27/98	407	0.5635	15	483	0.4263	20	3.4960	483	4.14	59
5/27/98	407	0.5635	16	475	0.6154	35	4.5711	475	7.37	59
5/27/98	407	0.5635	17	385	0.6792	31	5.2087	454	8.05	50
5/27/98	418	0.5672	6	58	0.3740	1	6.4000	342	1.72	10
5/27/98	418	0.5672	7	365	0.5478	20	4.9020	365	5.48	59
5/27/98	418	0.5672	8	391	0.4634	12	5.1600	391	3.07	59

5/27/98	418	0.5672	9	377	0.6585	23	5.6183	377	6.10	59
5/27/98	418	0.5672	10	360	0.6059	17	4.9406	360	4.72	59
5/27/98	418	0.5672	11	315	0.6158	20	4.4860	315	6.35	59
5/27/98	418	0.5672	12	355	0.5838	17	5.2735	355	4.79	59
5/27/98	418	0.5672	13	352	0.6284	21	4.4114	352	5.97	59
5/27/98	418	0.5672	14	413	0.5467	23	4.6826	413	5.57	59
5/27/98	418	0.5672	15	507	0.5661	21	5.8324	507	4.14	59
5/27/98	418	0.5672	16	599	0.5930	38	4.5095	599	6.34	59
5/27/98	418	0.5672	17	634	0.5290	25	5.6824	634	3.94	59
5/27/98	418	0.5672	18	181	0.4880	9	4.0944	712	4.97	15
5/28/98	407	0.3215	6	91	0.2540	2	4.1400	447	2.20	12
5/28/98	407	0.3215	7	741	0.2532	12	4.6633	741	1.62	59
5/28/98	407	0.3215	8	735	0.3121	20	4.9085	774	2.72	56
5/28/98	407	0.3215	9	382	0.3092	13	4.1169	433	3.40	52
5/28/98	407	0.3215	10	385	0.2275	6	3.6533	421	1.56	54
5/28/98	407	0.3215	11	286	0.2306	5	4.1280	286	1.75	59
5/28/98	407	0.3215	12	73	0.1448	1	3.6900	113	1.37	38
5/28/98	407	0.3215	13	36	0.5036	2	6.1250	54	5.56	39
5/28/98	407	0.3215	14	329	0.2481	4	5.4475	329	1.22	59
5/28/98	407	0.3215	15	598	0.3636	19	4.4232	598	3.18	59
5/28/98	407	0.3215	16	534	0.4772	23	5.1317	534	4.31	59
5/28/98	407	0.3215	17	662	0.4035	22	5.3391	662	3.32	59
5/28/98	418	0.6836	7	729	0.6398	46	4.8946	915	6.31	47
5/28/98	418	0.6836	8	840	0.6343	50	5.1198	840	5.95	59
5/28/98	418	0.6836	9	593	0.7827	49	5.2110	593	8.26	59
5/28/98	418	0.6836	10	526	0.5275	32	4.4475	526	6.08	59

5/28/98	418	0.6836	11	404	0.6306	25	4.8276	404	6.19	59
5/28/98	418	0.6836	12	401	0.6815	32	4.5894	483	7.98	49
5/28/98	418	0.6836	13	442	0.7401	33	5.5133	442	7.47	59
5/28/98	418	0.6836	14	468	0.8003	44	5.0000	468	9.40	59
5/28/98	418	0.6836	15	509	0.8150	47	5.1740	509	9.23	59
5/28/98	418	0.6836	16	434	0.6324	28	5.0846	434	6.45	59
5/28/98	418	0.6836	17	494	0.6733	33	5.0421	494	6.68	59
5/29/98	407	0.3460	13	620	0.3441	18	4.7544	892	2.90	41
5/30/98	407	0.8226	7	187	0.8194	19	5.5195	480	10.16	23
5/30/98	407	0.8226	8	299	0.9371	38	5.1784	299	12.71	59
5/30/98	407	0.8226	9	574	0.8809	54	5.4252	574	9.41	59
5/30/98	407	0.8226	10	458	0.9185	43	5.8416	458	9.39	59
5/30/98	407	0.8226	11	456	0.7041	33	4.9624	456	7.24	59
5/30/98	407	0.8226	12	534	0.7597	41	5.3568	534	7.68	59
5/30/98	407	0.8226	13	508	0.7671	42	4.4131	508	8.27	59
5/30/98	407	0.8226	14	548	0.8283	52	4.9731	567	9.49	57
5/30/98	418	0.5326	7	138	0.4046	6	3.7733	905	4.35	9
5/30/98	418	0.5326	8	898	0.5334	45	5.2787	898	5.01	59
5/30/98	418	0.5326	9	1021	0.5545	62	4.7669	1021	6.07	59
5/30/98	418	0.5326	10	911	0.5326	50	4.3884	911	5.49	59
5/30/98	418	0.5326	11	893	0.5782	58	4.6852	893	6.49	59
5/30/98	418	0.5326	12	901	0.5106	44	4.8018	901	4.88	59
5/30/98	418	0.5326	13	919	0.5439	55	4.6033	919	5.98	59
5/30/98	418	0.5326	14	1039	0.5444	59	4.8144	1039	5.68	59
5/30/98	418	0.5326	15	1364	0.5439	67	4.9924	1364	4.91	59
5/30/98	418	0.5326	16	970	0.5374	52	5.0596	970	5.36	59

5/30/98	418	0.5326	17	467	0.3842	17	4.8365	1198	3.64	23
6/1/98	407	0.4440	7	539	0.4239	11	4.8764	589	2.04	54
6/1/98	407	0.4440	8	695	0.4798	29	4.0328	695	4.17	59
6/1/98	407	0.4440	9	645	0.4832	17	5.3329	645	2.64	59
6/1/98	407	0.4440	10	704	0.4335	22	4.1295	704	3.13	59
6/1/98	407	0.4440	11	693	0.3900	12	3.7242	693	1.73	59
6/1/98	407	0.4440	12	651	0.4078	20	3.8880	651	3.07	59
6/1/98	407	0.4440	13	679	0.4549	26	4.5050	679	3.83	59
6/1/98	407	0.4440	14	576	0.4819	19	4.3516	576	3.30	59
6/1/98	407	0.4440	15	668	0.4667	21	4.4286	668	3.14	59
6/1/98	407	0.4440	16	418	0.4506	18	3.8367	418	4.31	59
6/1/98	407	0.4440	17	703	0.4206	16	4.0844	703	2.28	59
6/1/98	418	0.3902	7	84	0.2963	1	5.1300	215	1.19	23
6/1/98	418	0.3902	8	175	0.4211	9	4.7811	175	5.14	59
6/1/98	418	0.3902	9	209	0.4046	8	5.2838	209	3.83	59
6/1/98	418	0.3902	10	223	0.3417	7	6.0929	223	3.14	59
6/1/98	418	0.3902	11	175	0.5112	12	4.7092	175	6.86	59
6/1/98	418	0.3902	12	163	0.4082	5	4.0060	163	3.07	59
6/1/98	418	0.3902	13	123	0.3567	6	3.3417	125	4.88	58
6/1/98	418	0.3902	14	165	0.3419	5	5.8900	165	3.03	59
6/1/98	418	0.3902	15	110	0.5553	4	6.2250	112	3.64	58
6/1/98	418	0.3902	16	97	0.4115	2	6.9500	97	2.06	59
6/1/98	418	0.3902	17	129	0.2336	3	3.9333	131	2.33	58
6/2/98	407	0.4439	7	983	0.3819	34	4.2562	1000	3.46	58
6/2/98	407	0.4439	8	724	0.4299	28	4.5611	724	3.87	59
6/2/98	407	0.4439	9	298	0.3938	13	3.5892	586	4.36	30

6/2/98	407	0.4439	10	181	0.5087	8	4.6888	254	4.42	42
6/2/98	407	0.4439	11	309	0.4140	13	4.2808	309	4.21	59
6/2/98	407	0.4439	12	341	0.4480	19	3.5616	341	5.57	59
6/2/98	407	0.4439	13	350	0.3959	14	3.7186	350	4.00	59
6/2/98	407	0.4439	14	392	0.5067	17	4.4465	392	4.34	59
6/2/98	407	0.4439	15	345	0.5336	19	5.1095	345	5.51	59
6/2/98	407	0.4439	16	444	0.5053	23	4.9809	444	5.18	59
6/2/98	407	0.4439	17	224	0.5156	13	4.5031	441	5.80	30
6/2/98	418	0.3202	6	433	0.2618	11	3.2645	594	2.54	43
6/2/98	418	0.3202	7	755	0.3028	20	4.4905	755	2.65	59
6/2/98	418	0.3202	8	859	0.2935	17	4.7294	859	1.98	59
6/2/98	418	0.3202	9	823	0.2844	15	4.2987	823	1.82	59
6/2/98	418	0.3202	10	888	0.3518	25	4.5124	888	2.82	59
6/2/98	418	0.3202	11	859	0.3310	25	4.5328	859	2.91	59
6/2/98	418	0.3202	12	869	0.3471	21	4.9476	869	2.42	59
6/2/98	418	0.3202	13	618	0.3958	24	4.9863	618	3.88	59
6/2/98	418	0.3202	14	622	0.3278	19	4.5905	622	3.05	59
6/2/98	418	0.3202	15	636	0.2864	18	4.5506	736	2.83	51
6/3/98	407	0.2916	6	1012	0.3672	36	4.4781	1012	3.56	59
6/3/98	407	0.2916	7	1187	0.2642	16	5.0206	1187	1.35	59
6/3/98	407	0.2916	8	1078	0.2976	16	5.4488	1078	1.48	59
6/3/98	407	0.2916	9	1178	0.2801	19	4.0216	1178	1.61	59
6/3/98	407	0.2916	10	1289	0.3393	38	4.8371	1289	2.95	59
6/3/98	407	0.2916	11	1018	0.2823	23	4.0487	1018	2.26	59
6/3/98	407	0.2916	12	1136	0.2229	16	4.1381	1136	1.41	59
6/3/98	407	0.2916	13	1169	0.2751	21	5.2943	1169	1.80	59

6/3/98	407	0.2916	14	1181	0.2767	30	4.3460	1181	2.54	59
6/3/98	407	0.2916	15	1168	0.3104	32	4.3941	1168	2.74	59
6/3/98	407	0.2916	16	215	0.3089	5	5.5400	906	2.33	14
6/3/98	418	0.2995	5	106	0.3770	3	3.1900	1042	2.83	6
6/3/98	418	0.2995	6	1087	0.2967	22	4.6359	1125	2.02	57
6/3/98	418	0.2995	7	1712	0.3379	37	5.7908	1712	2.16	59
6/3/98	418	0.2995	8	1508	0.2458	22	4.2341	1508	1.46	59
6/3/98	418	0.2995	9	1355	0.2710	29	4.9907	1355	2.14	59
6/3/98	418	0.2995	10	822	0.2095	10	5.6090	822	1.22	59
6/3/98	418	0.2995	11	896	0.2788	23	4.2678	896	2.57	59
6/3/98	418	0.2995	12	796	0.2894	21	5.1943	958	2.64	49
6/3/98	418	0.2995	13	687	0.3564	23	4.7874	989	3.35	41
6/3/98	418	0.2995	14	812	0.3299	26	4.6077	812	3.20	59
6/3/98	418	0.2995	15	906	0.3917	39	4.1879	906	4.30	59
6/3/98	418	0.2995	16	886	0.3019	22	5.0941	1376	2.48	38
6/9/98	407	0.4538	11	314	0.3997	6	3.8600	394	1.91	47
6/9/98	407	0.4538	12	407	0.4660	16	3.5638	407	3.93	59
6/9/98	407	0.4538	13	224	0.5680	9	5.1922	224	4.02	59
6/9/98	407	0.4538	14	135	0.5346	4	5.9600	319	2.96	25
6/9/98	407	0.4538	15	70	0.4733	4	3.0325	318	5.71	13
6/9/98	407	0.4538	16	347	0.4051	7	4.1186	347	2.02	59
6/9/98	407	0.4538	17	127	0.3831	4	3.6575	394	3.15	19
6/11/98	407	0.4847	10	261	0.5331	11	4.4773	453	4.21	34
6/11/98	407	0.4847	11	435	0.4595	18	4.1467	435	4.14	59
6/11/98	407	0.4847	12	488	0.3582	8	4.5500	488	1.64	59
6/11/98	407	0.4847	13	465	0.4505	8	4.7775	465	1.72	59

6/11/98	407	0.4847	14	493	0.5408	26	3.9888	493	5.27	59
6/11/98	407	0.4847	15	417	0.4845	13	4.1154	417	3.12	59
6/11/98	407	0.4847	16	445	0.5119	18	4.2072	445	4.04	59
6/11/98	407	0.4847	17	397	0.5596	16	5.7225	397	4.03	59
6/11/98	407	0.4847	18	240	0.5119	9	4.3278	644	3.75	22
6/16/98	407	0.5129	11	418	0.5234	17	5.3888	418	4.07	59
6/16/98	407	0.5129	12	473	0.4925	13	4.4438	473	2.75	59
6/16/98	407	0.5129	13	354	0.5275	17	4.6706	402	4.80	52
6/18/98	407	0.4714	4	126	0.4091	5	3.7740	413	3.97	18
6/18/98	407	0.4714	11	370	0.4321	10	5.1300	455	2.70	48
6/18/98	407	0.4714	12	477	0.4002	10	4.6780	477	2.10	59
6/18/98	407	0.4714	13	462	0.4416	15	4.4127	462	3.25	59
6/18/98	407	0.4714	14	413	0.5617	19	4.6989	413	4.60	59
6/18/98	407	0.4714	15	426	0.5712	18	4.6394	426	4.23	59
6/18/98	407	0.4714	16	91	0.3642	1	3.8500	413	1.10	13

Figure 2 Comparison Vermont Vehicles Distribution versus New York

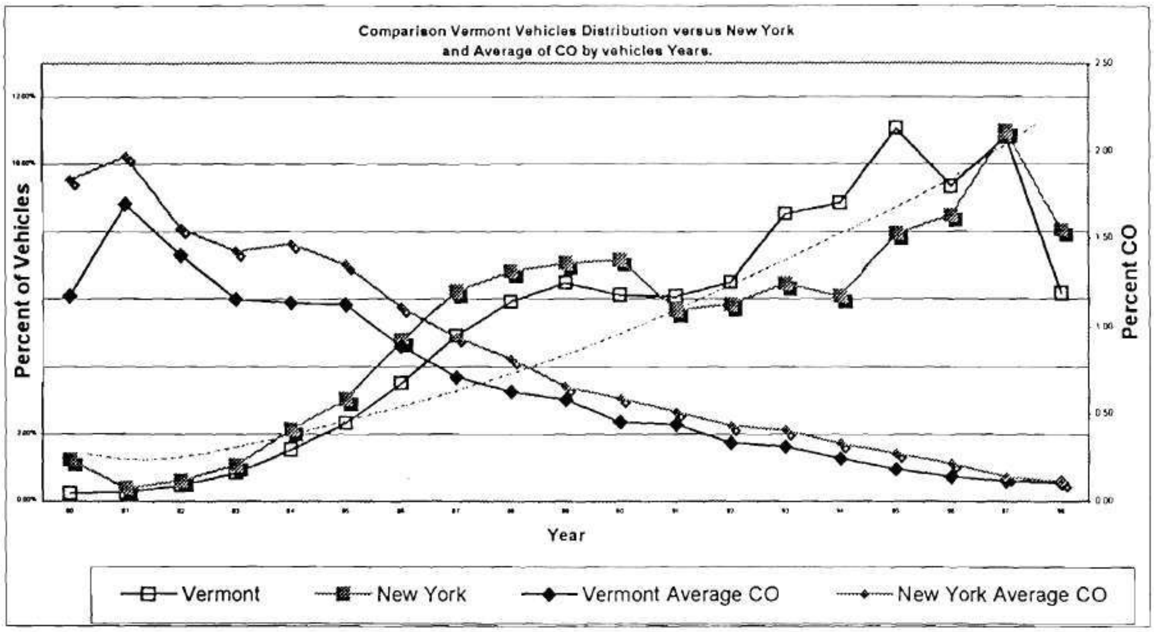


Figure 3 Average CO Passenger versus Commercial

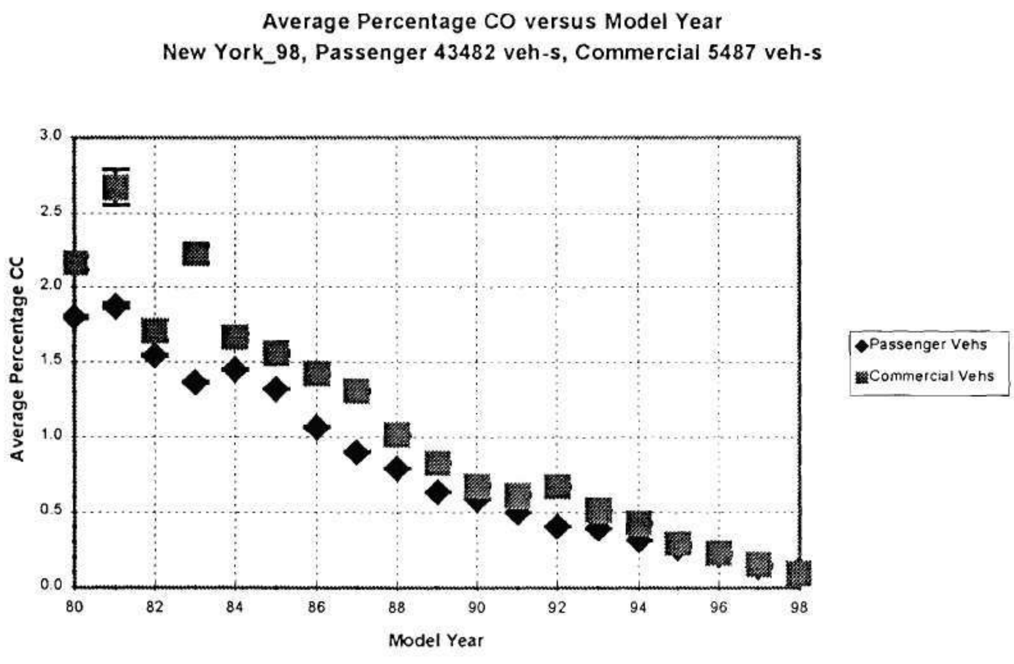


Figure 4 Average HC Passenger versus Commercial

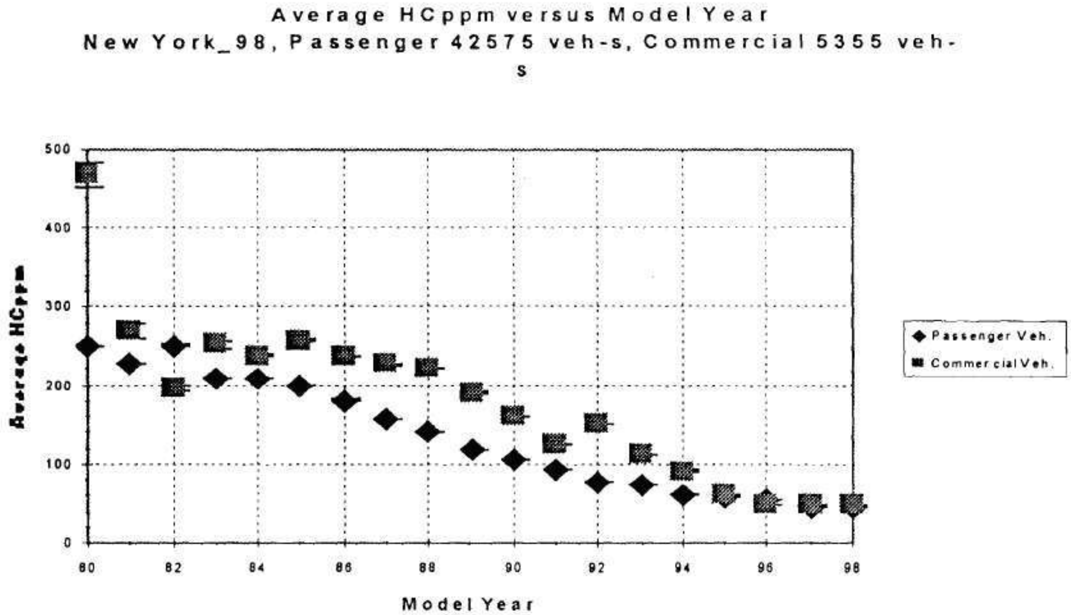


Figure 5 Average NOx Passenger versus Commercial

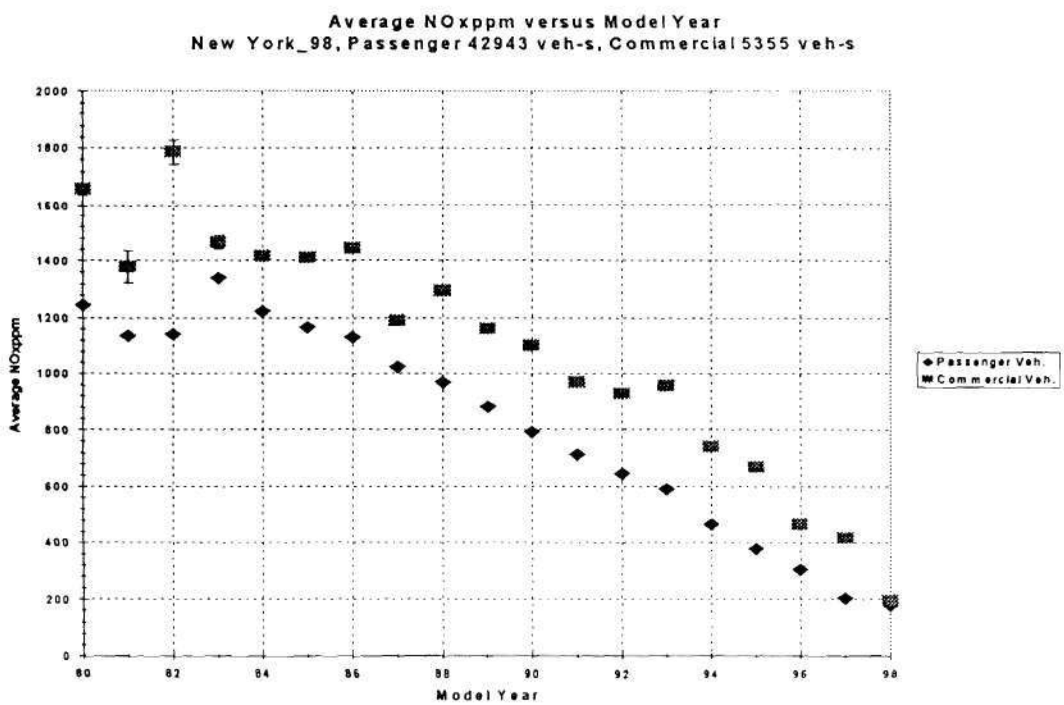


Figure 6 Average Co versus Odometer Reading for Taxi

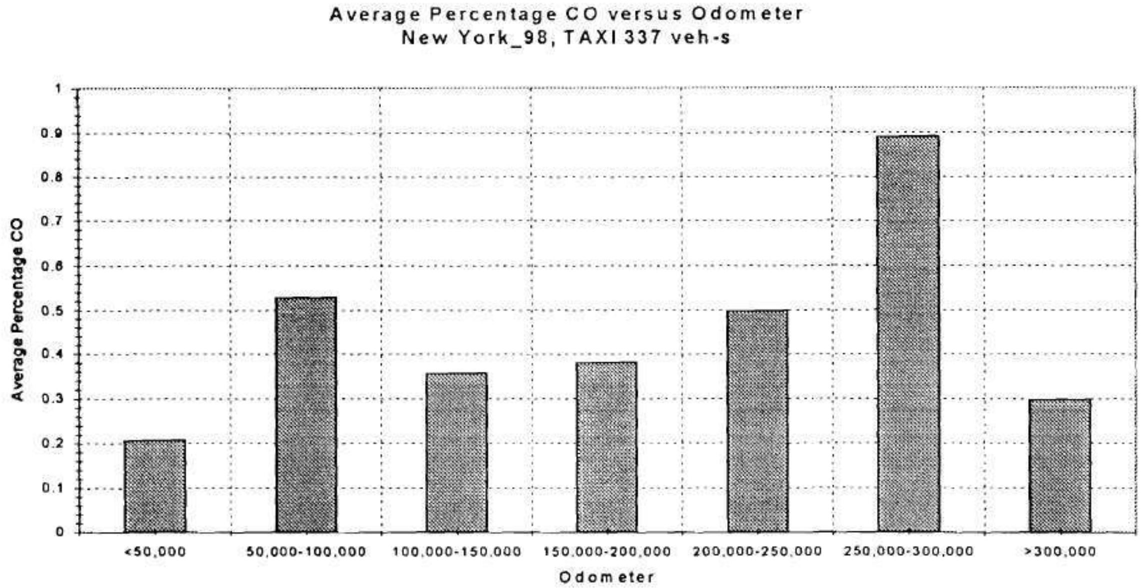


Figure 7 Average HC versus Odometer Reading for Taxi

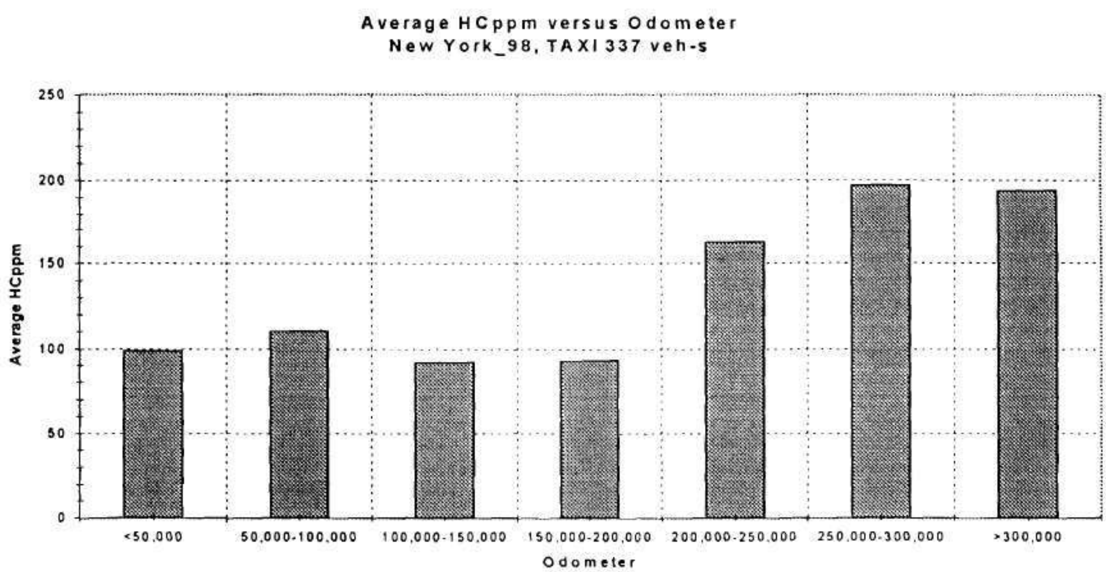


Figure 8 Average NOx versus Odometer Reading for Taxi

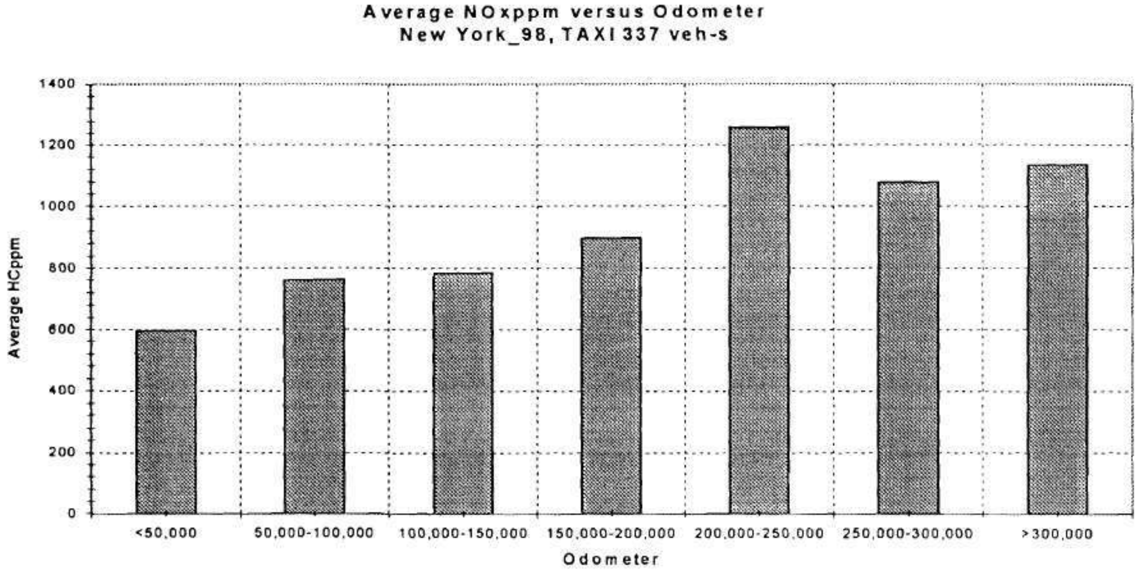


Figure 9 Dependence of Fraction and Contribution for High Emitters

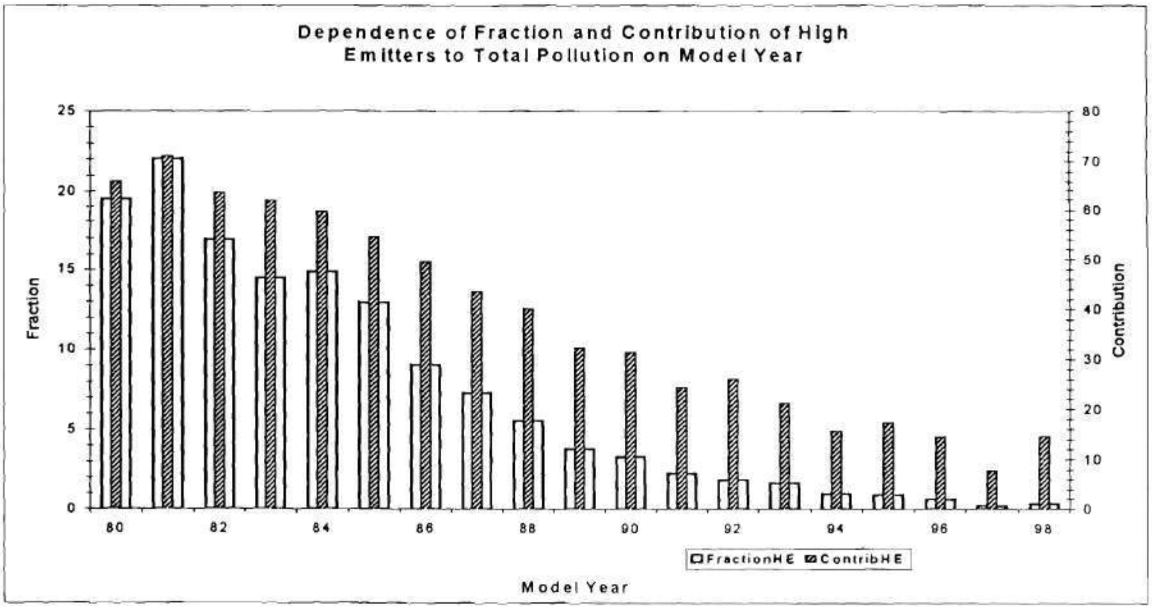


Figure 10 Contribution of Vehicles Different Age Group

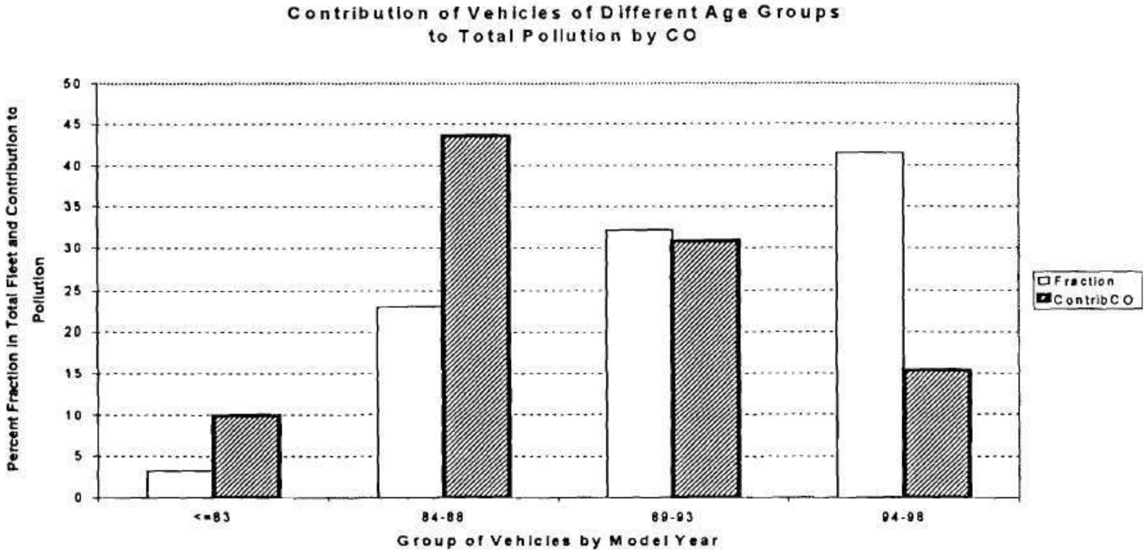


Figure 11 Comparison of High Emitters with CO > 2.4% and 3.6%

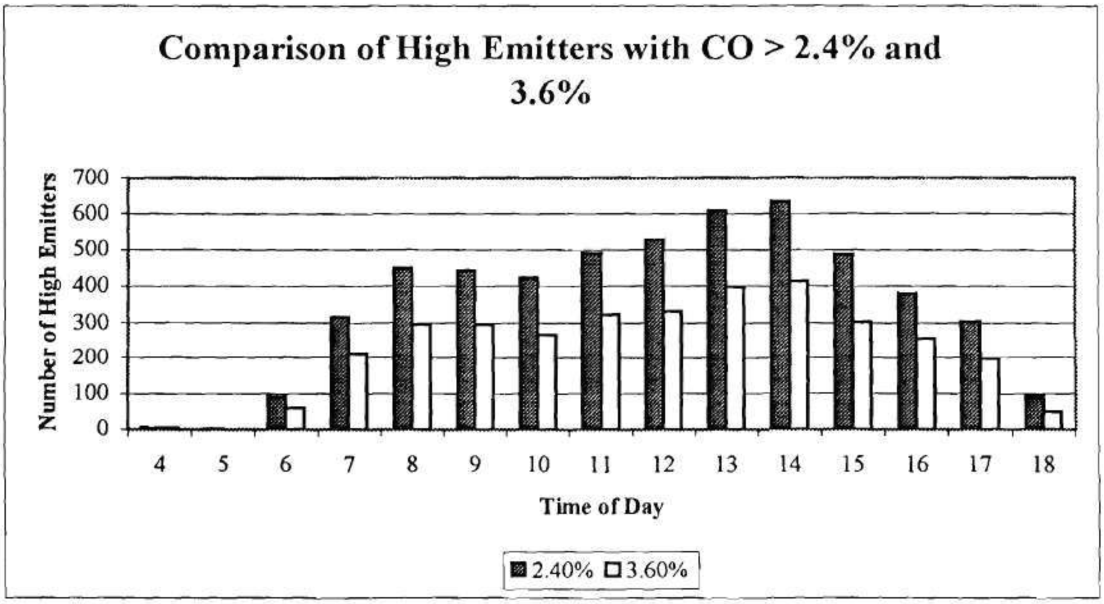


Figure 12 Percent of High Emitters (CO > 2.4%) for each hour.

Total for all days and sites.

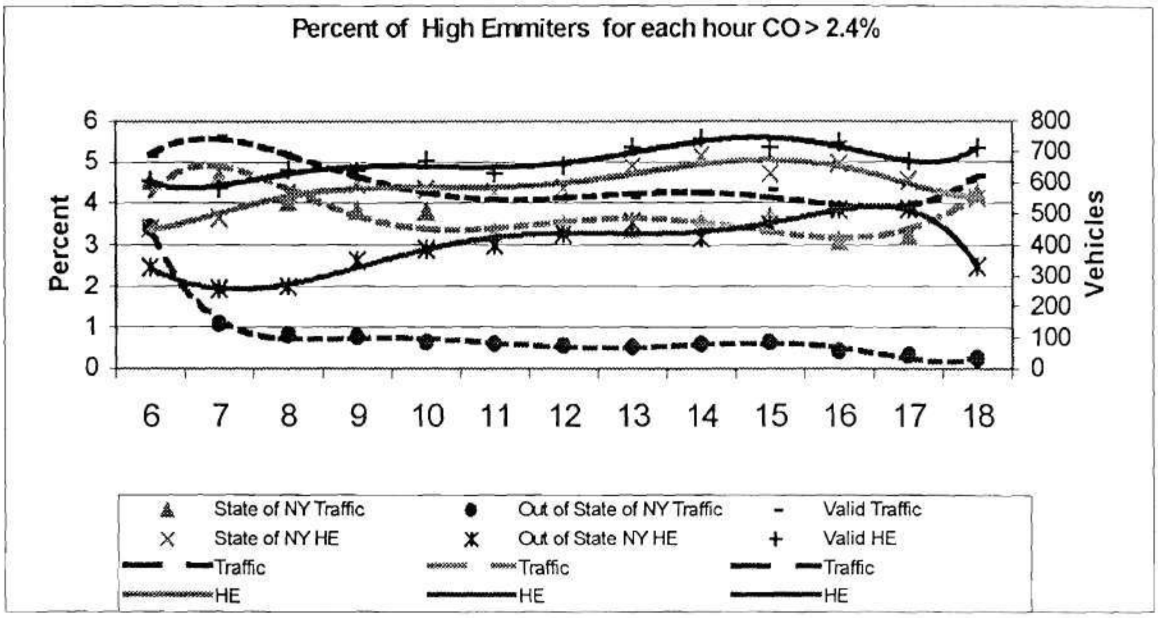


Figure 13 Percent of High Emitters for Inbound and Outbound Sites

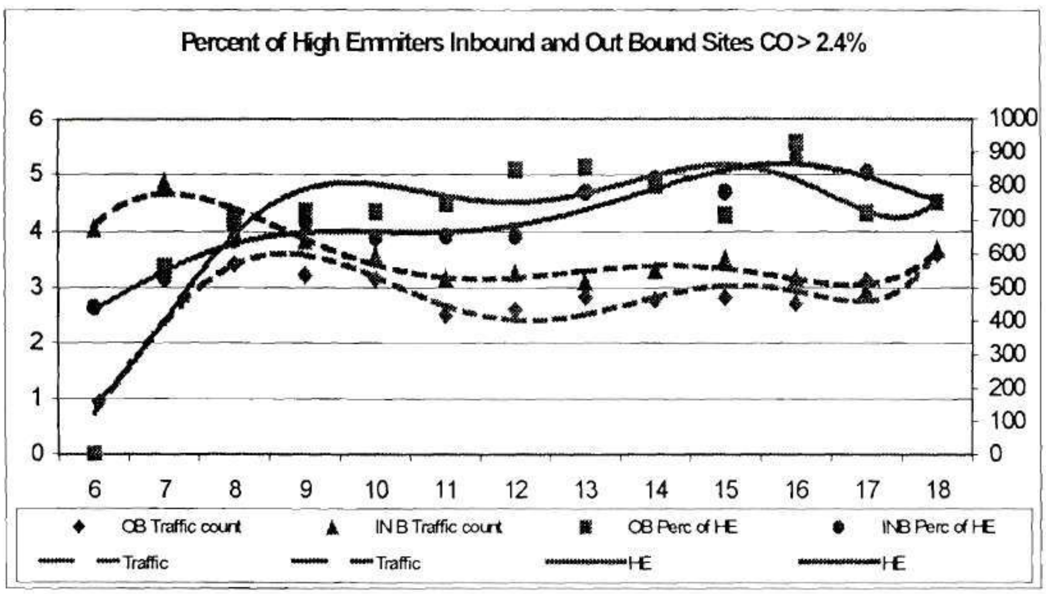


Figure 14 **May 14 RSD407**

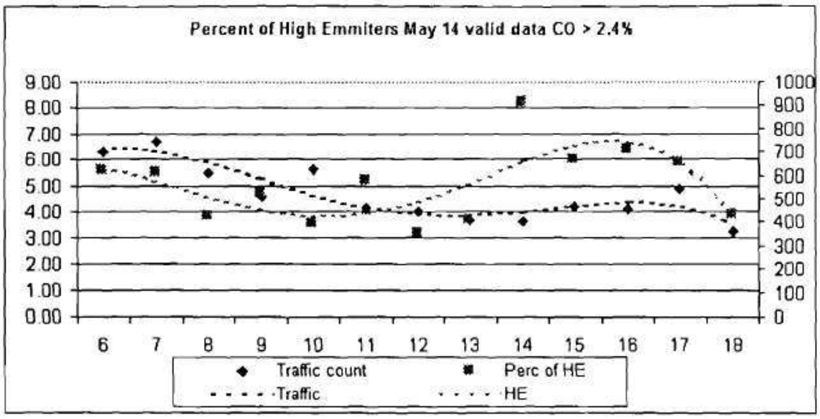


Figure 15 **May 15 RSD407**

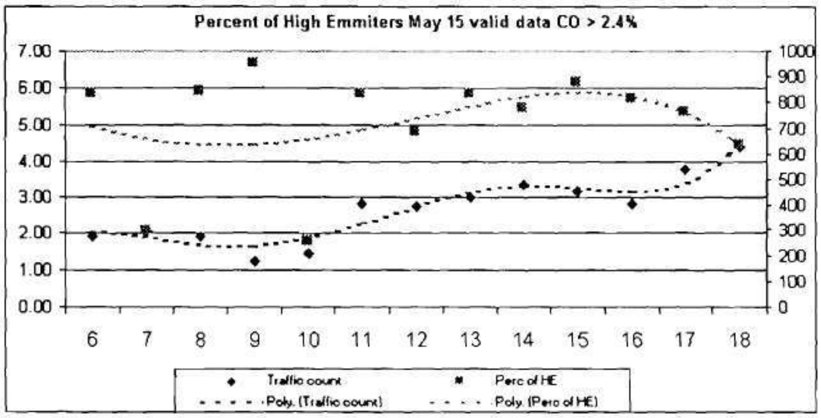


Figure 16 **May 16 RSD407**

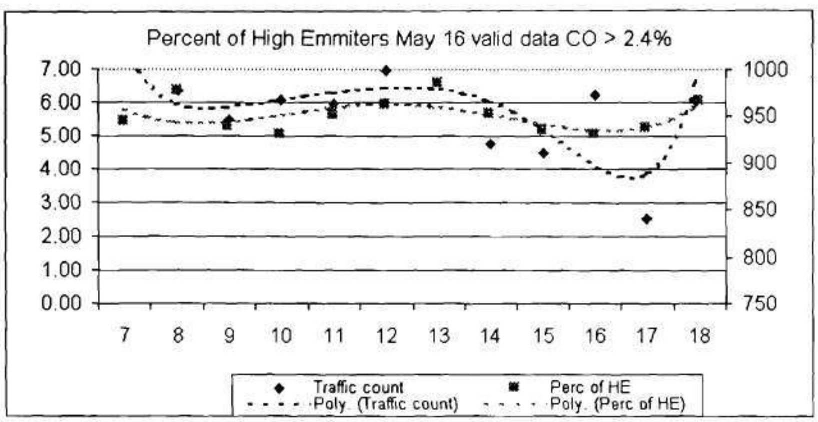


Figure 17 **May 17 RSD407**

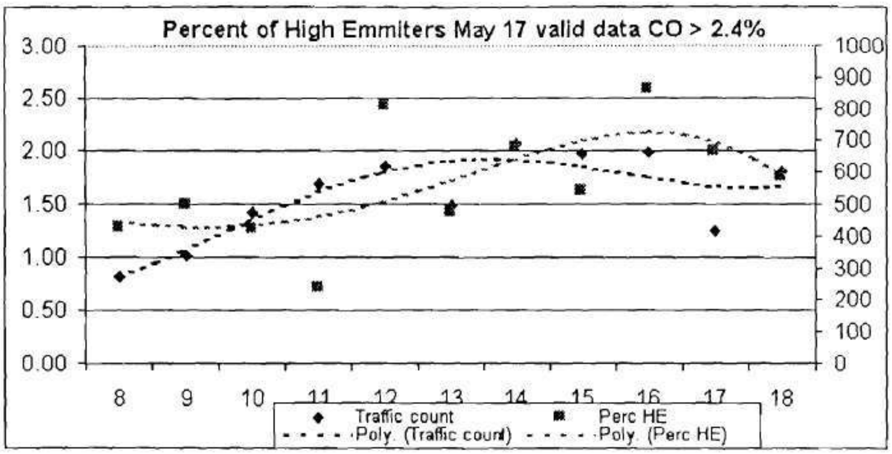


Figure 18 **May 18 RSD407**

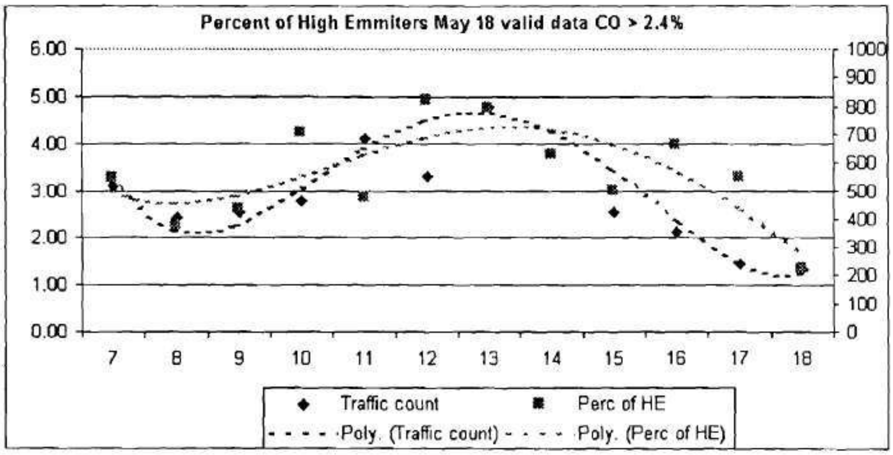


Figure 19 **May 19 RSD407**

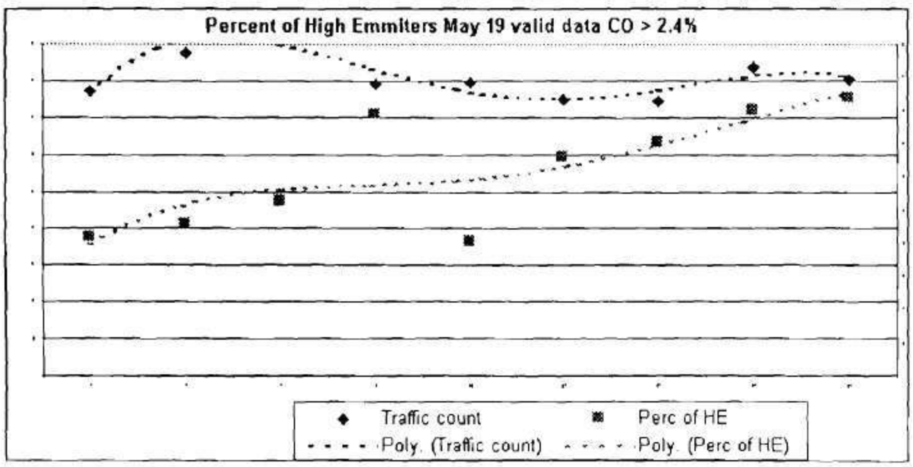


Figure 20 May 20 RSD407

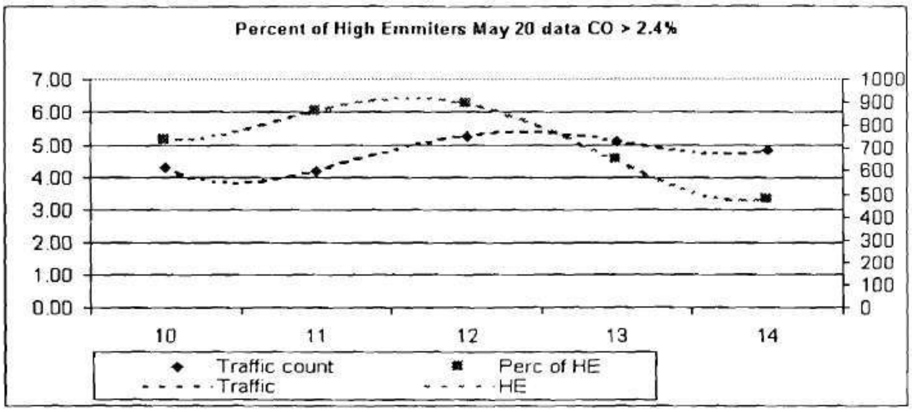


Figure 21 May 21 RSD407

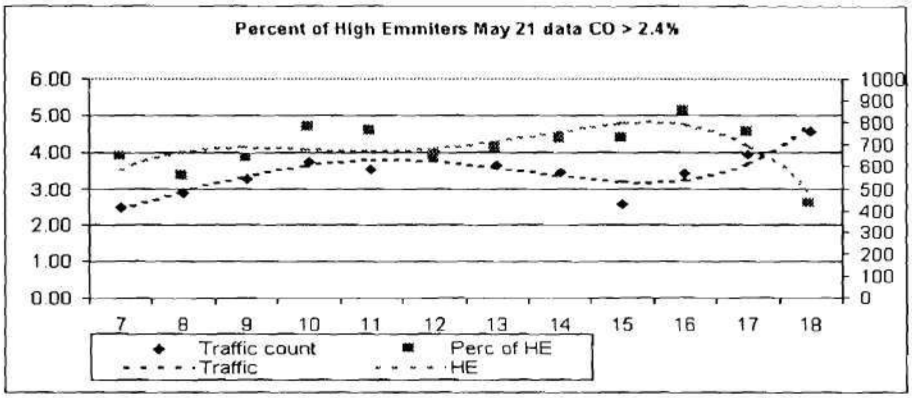


Figure 22 May 22 RSD407

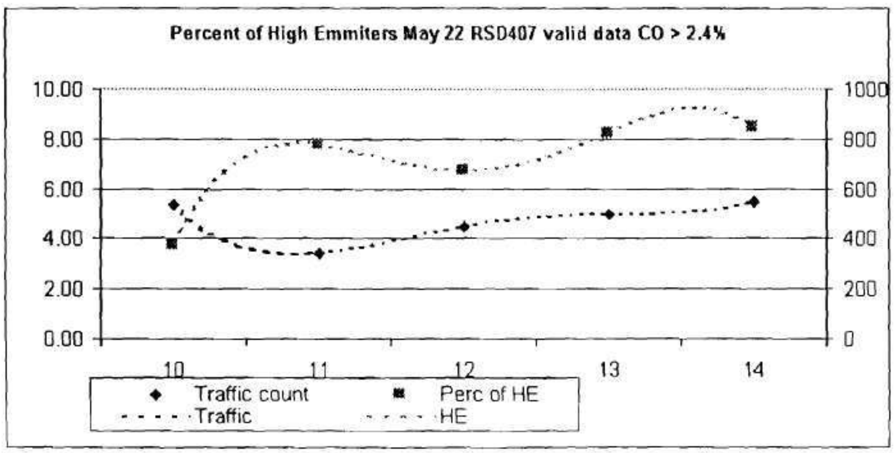


Figure 23 **May 22 RSD418**

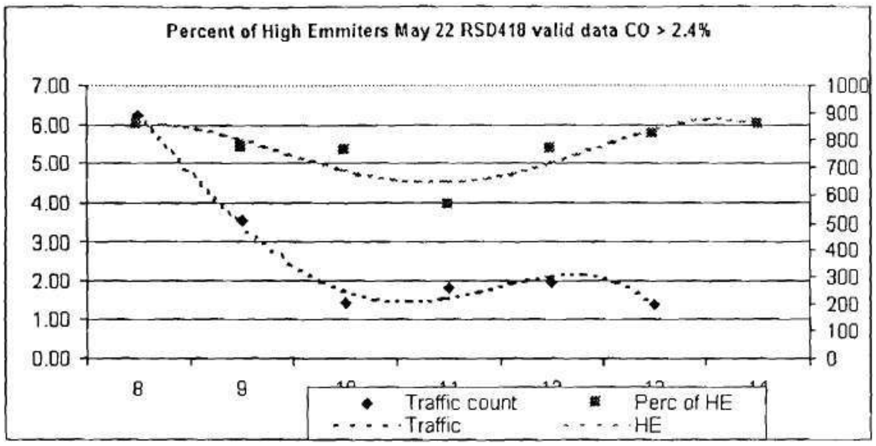


Figure 24 **May 26 RSD407**

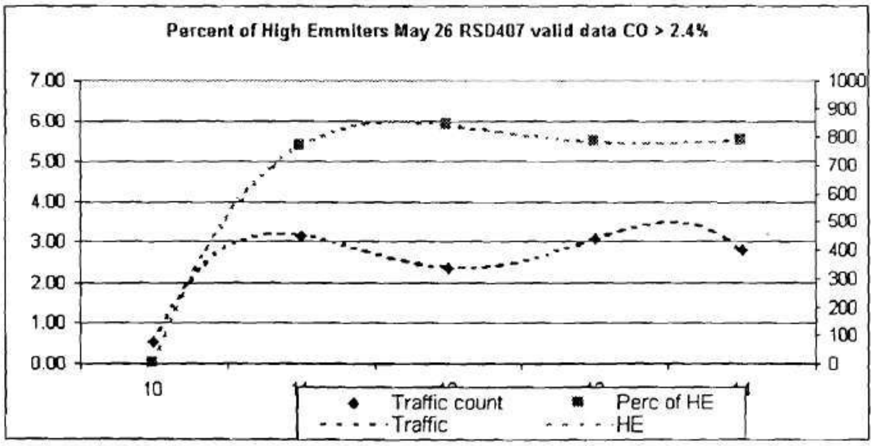


Figure 25 **May 26 RSD418**

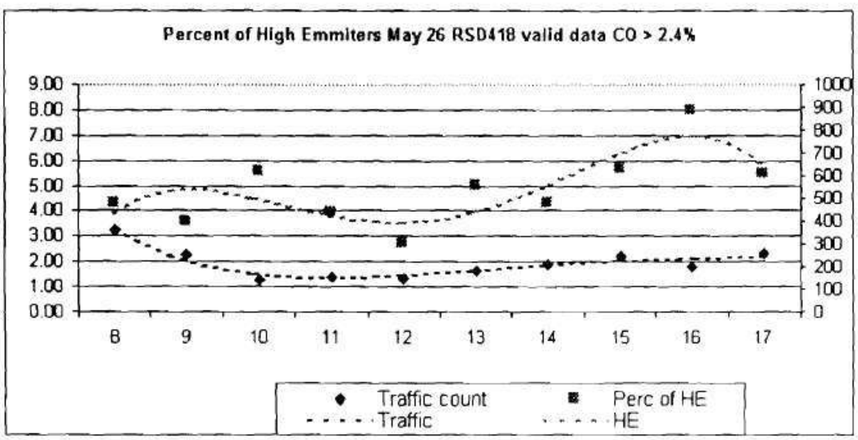


Figure 26 **May 27 RSD407**

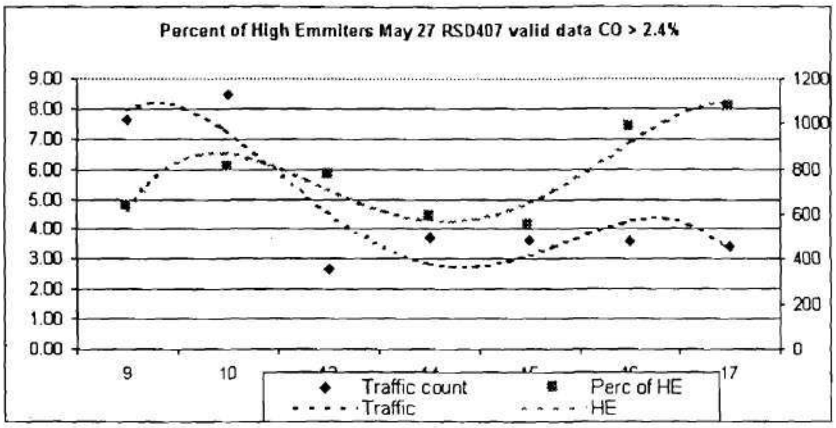


Figure 27 **May 27 RSD418**

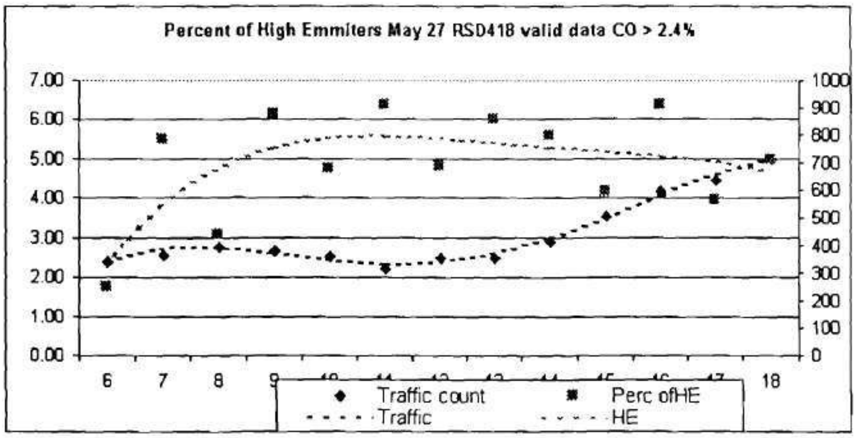


Figure 28 **May 28 RSD407**

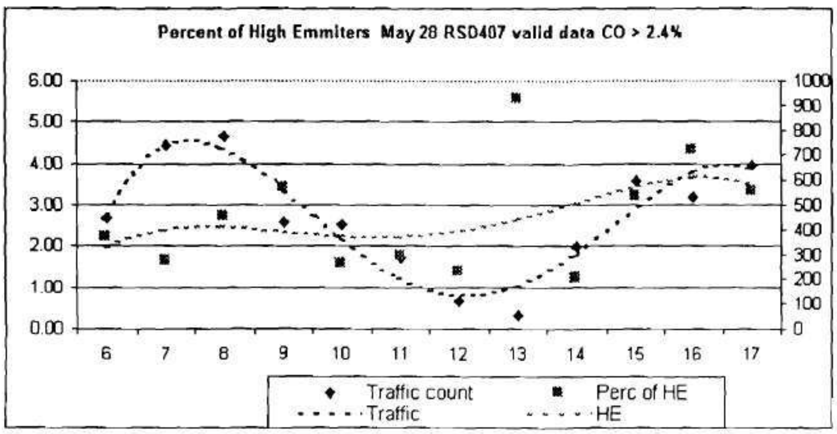


Figure 29 May28 RSD418

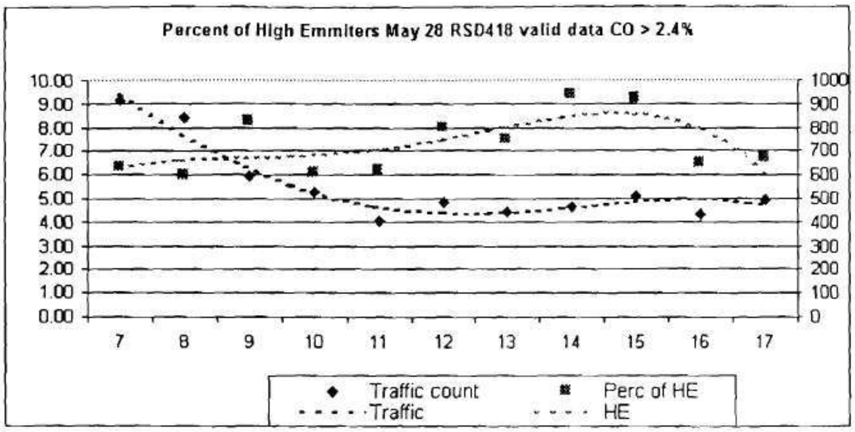


Figure 30 May 30 RSD407

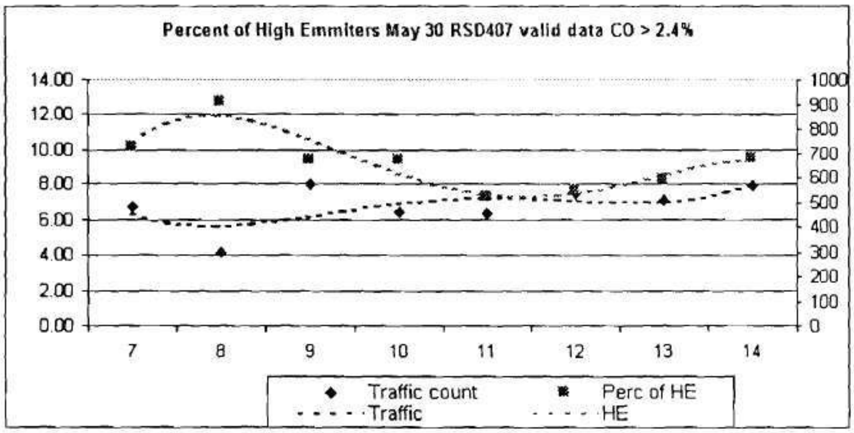


Figure 31 May 30 RSD418

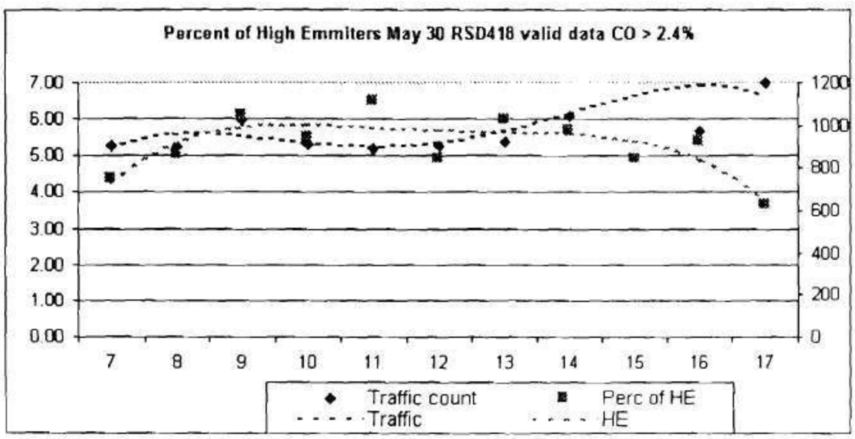


Figure 32 June 1 RSD407

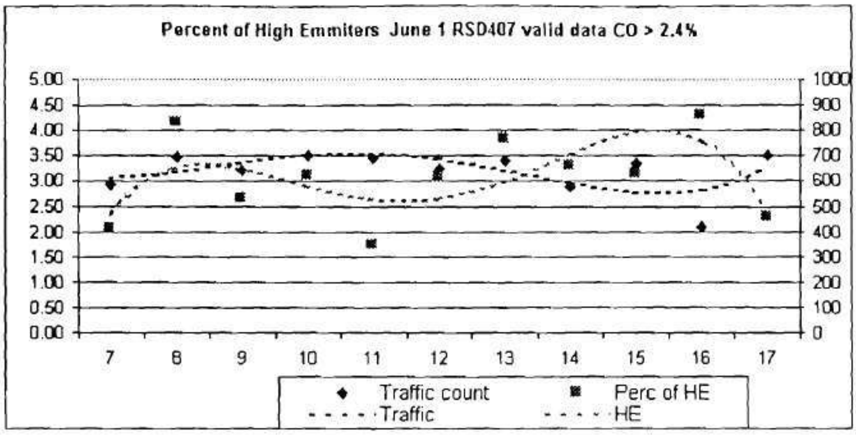


Figure 33 June 1 RSD418

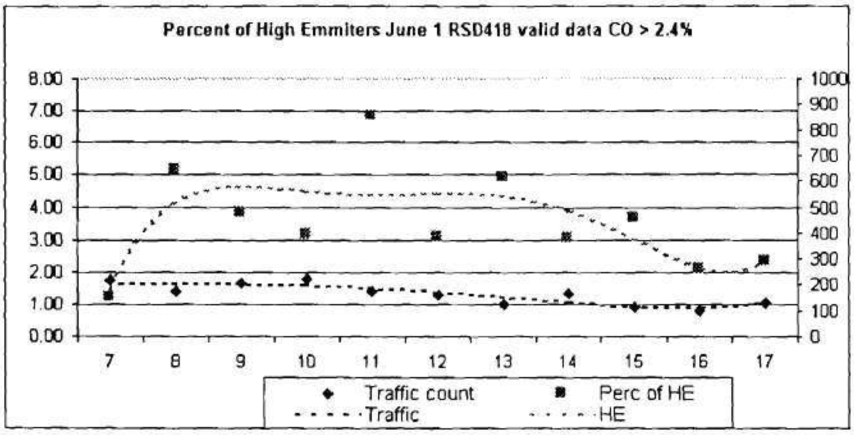


Figure 34 June 2 RSD407

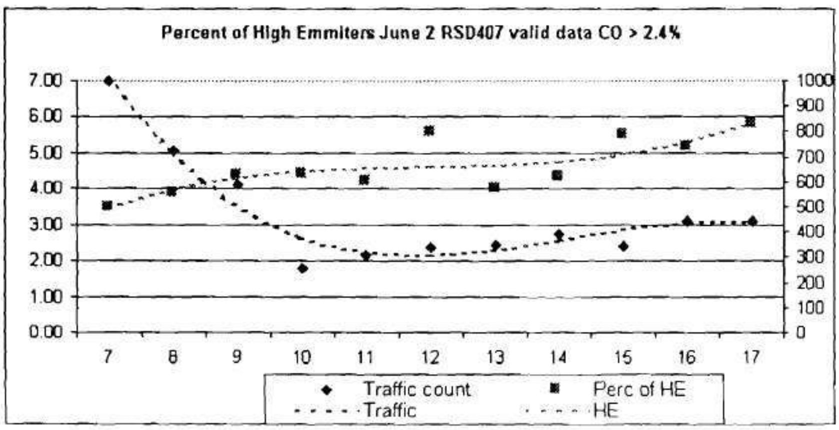


Figure 35 **June 2 RSD418**

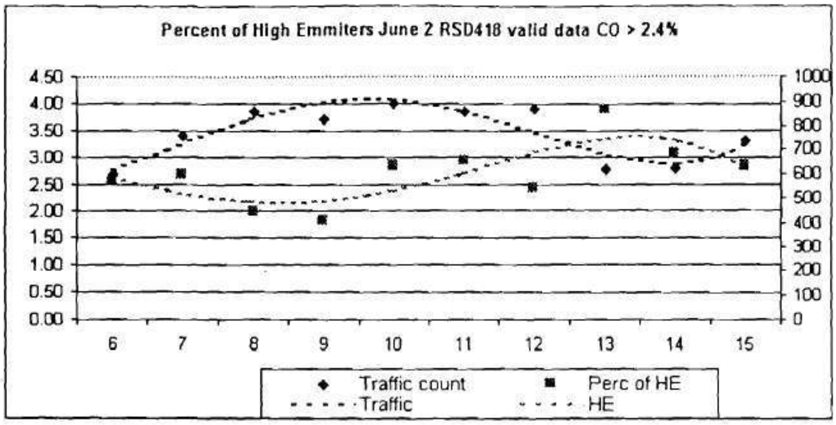


Figure 36 **June 3 RSD407**

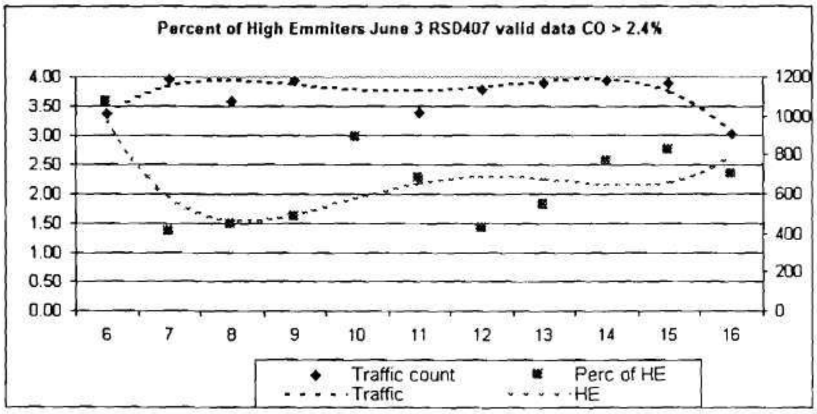


Figure 37 **June 3 RSD418**

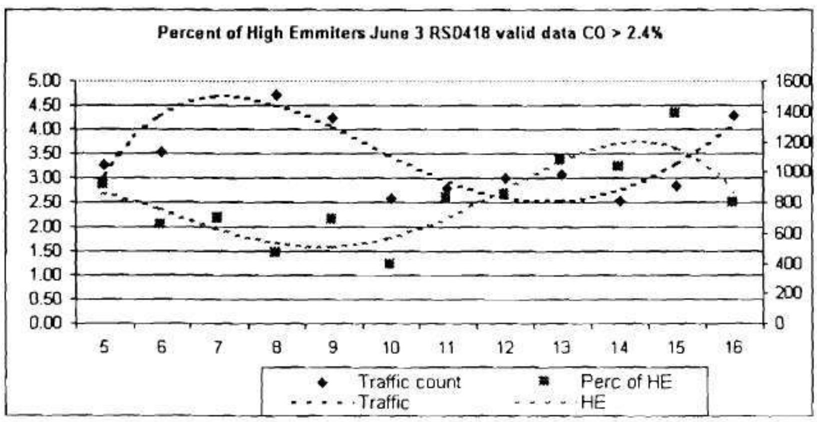


Figure 38 June 9 RSD407

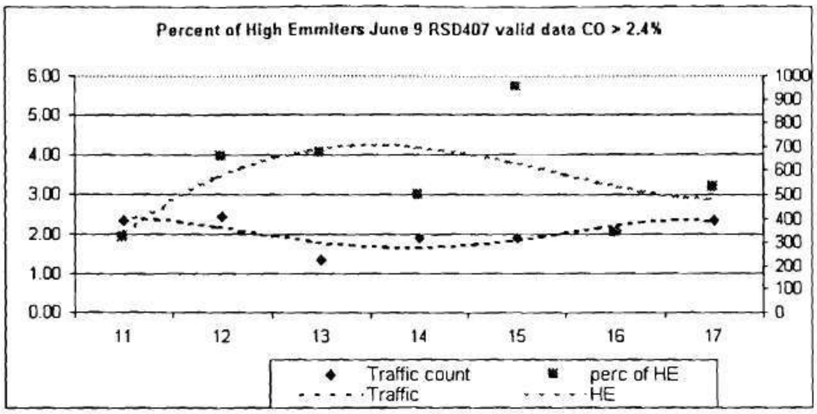


Figure 39 June 11 RSD407

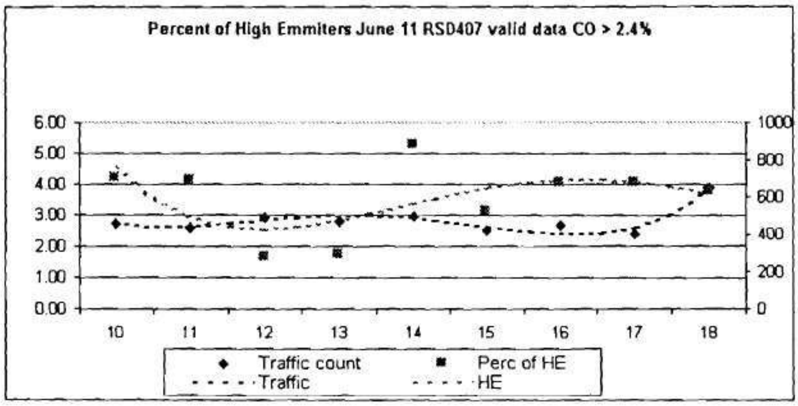


Figure 40 June 16 RSD407

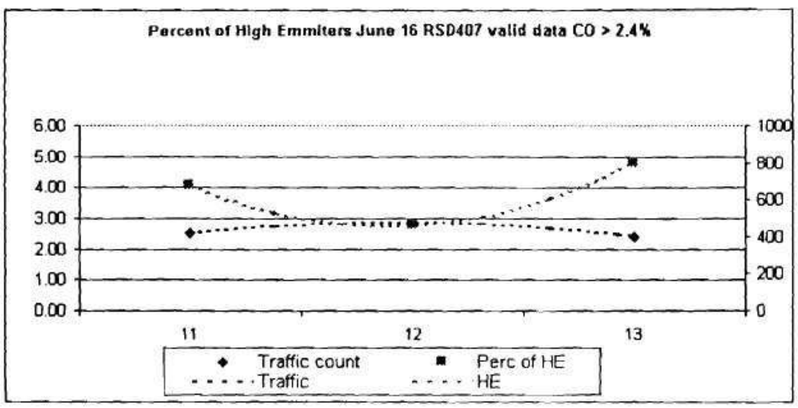


Figure 41 June 18 RSD407

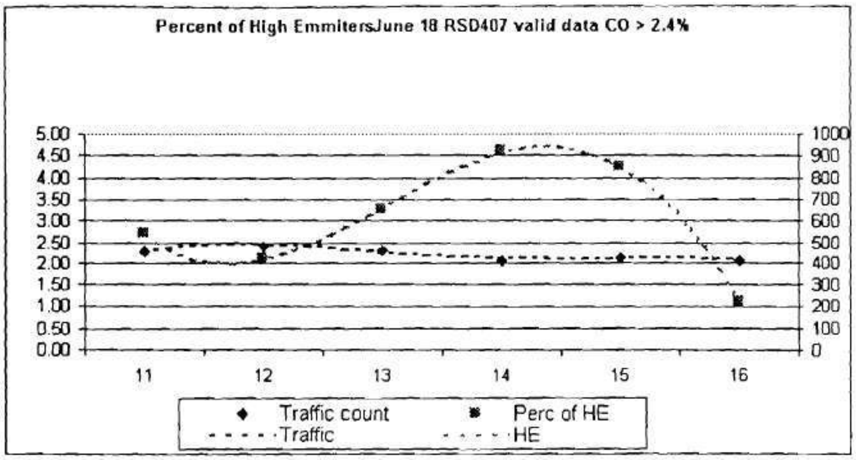


Figure 42 Carbon Monoxide Certification Results for Unit R418

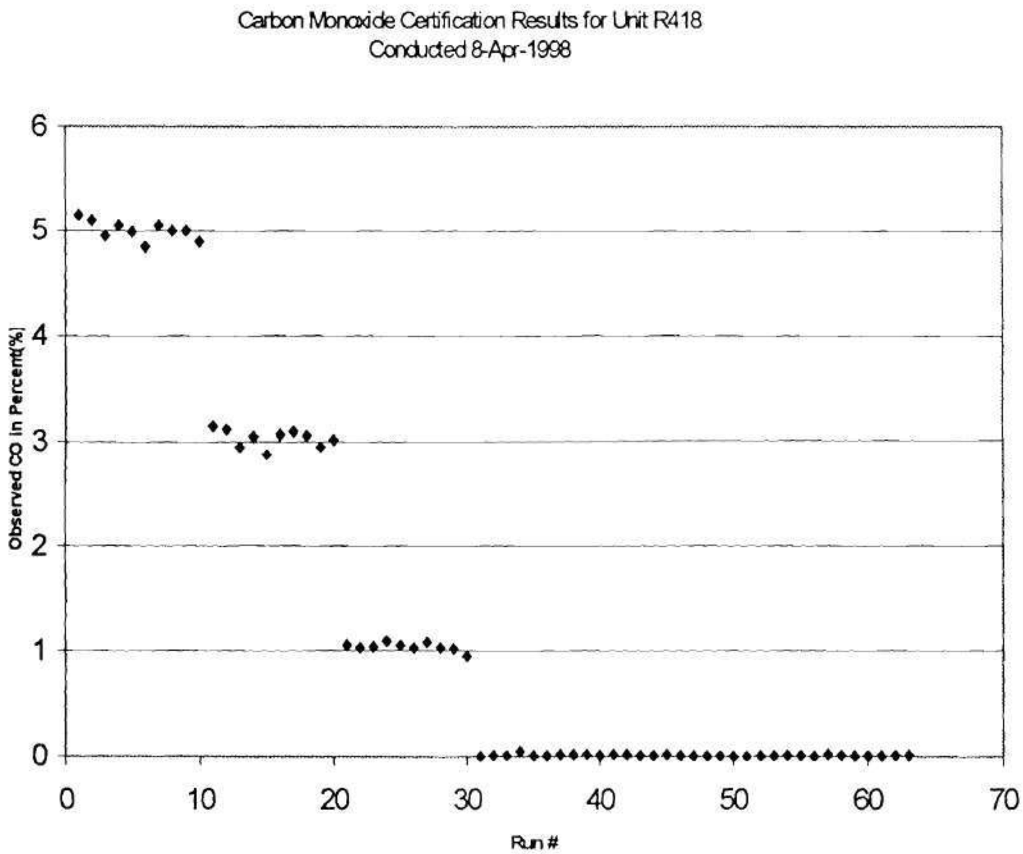


Figure 43 Average Remote Sensing and IM240 CO by MY

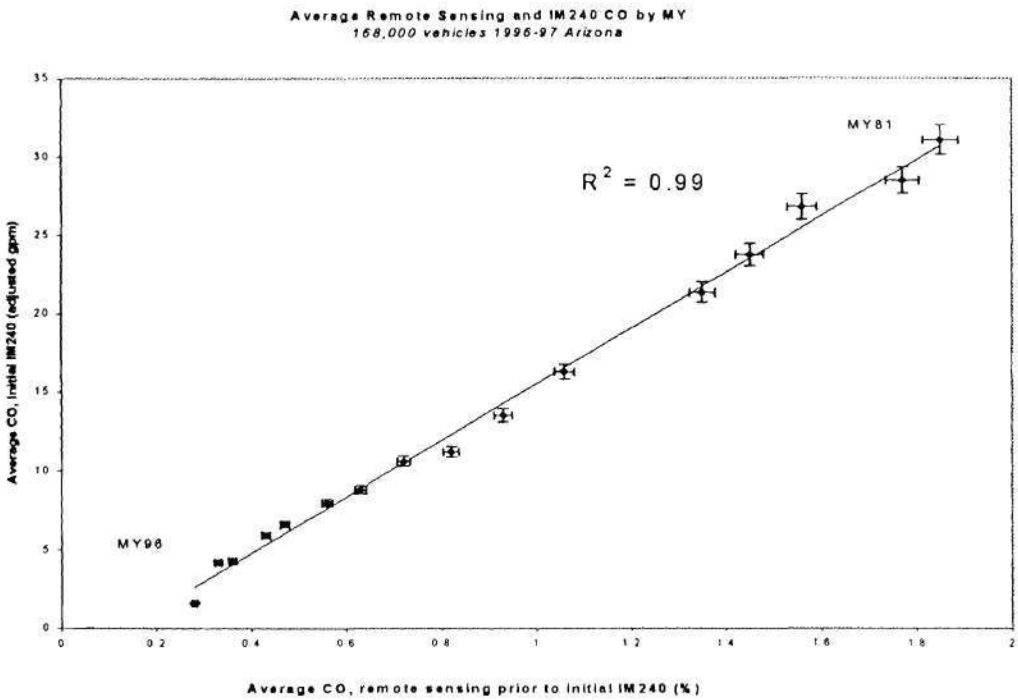


Figure 44 CO for Repeat Observations versus CO for First Observation

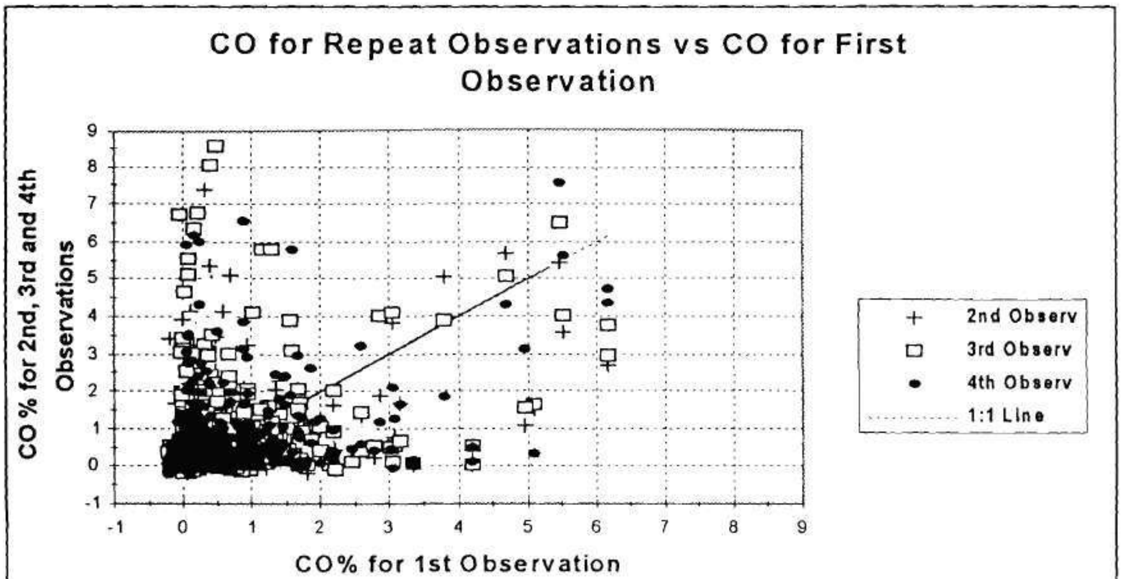


Figure 45 Histograms of Four Independent Observations,

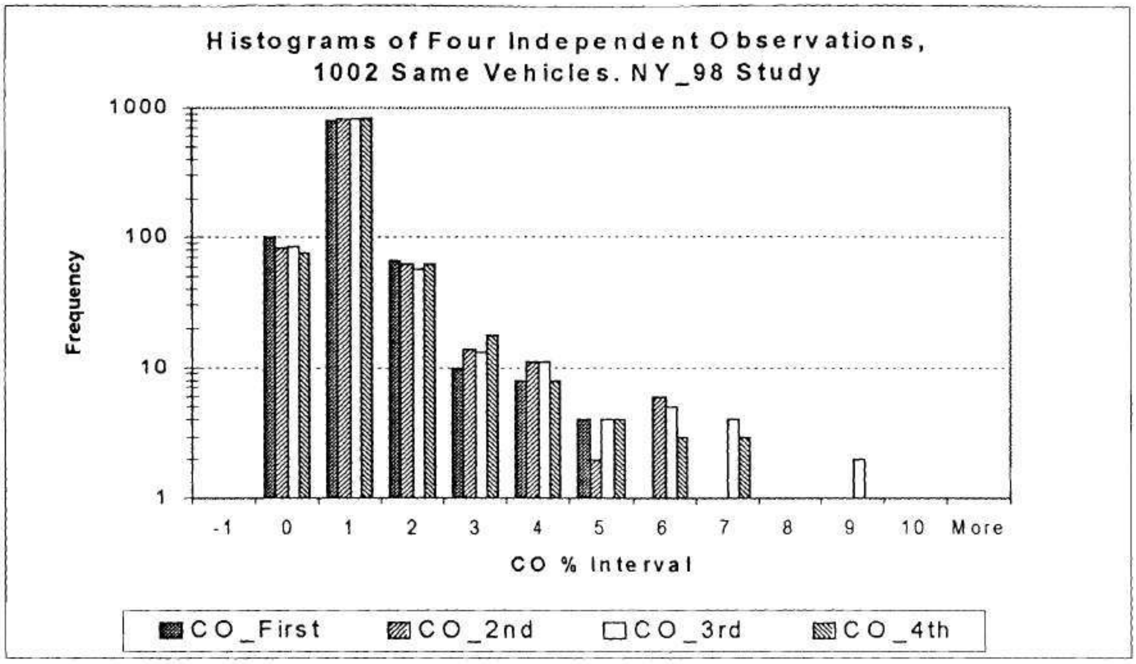


Figure 46 Spread of Readings for Vehicles with CO avg. < 1 %.

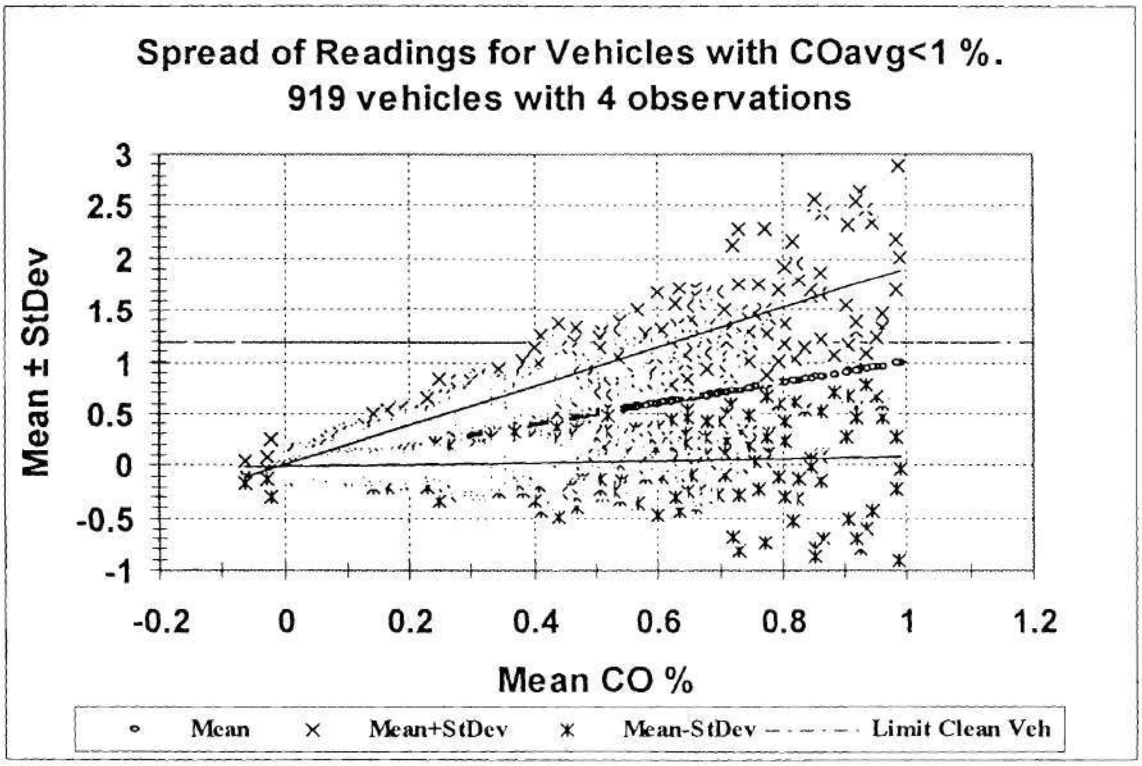


Figure 47 Reproducibility of High Emitter Data

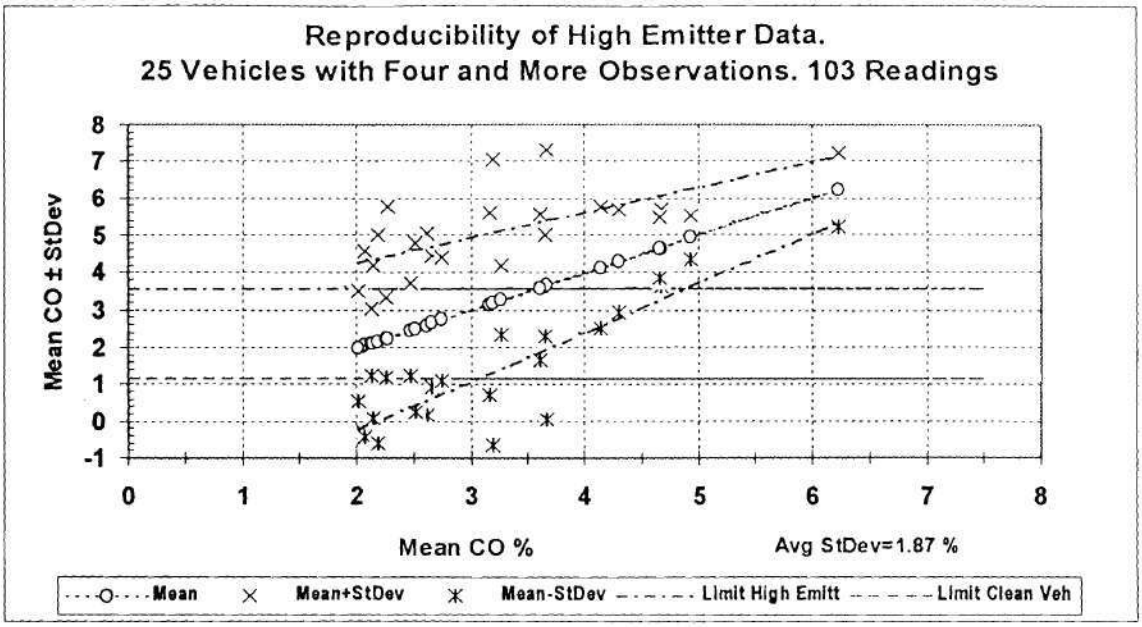


Figure 48 Distribution of Reading of 79 Clean Vehicles Four and more observation

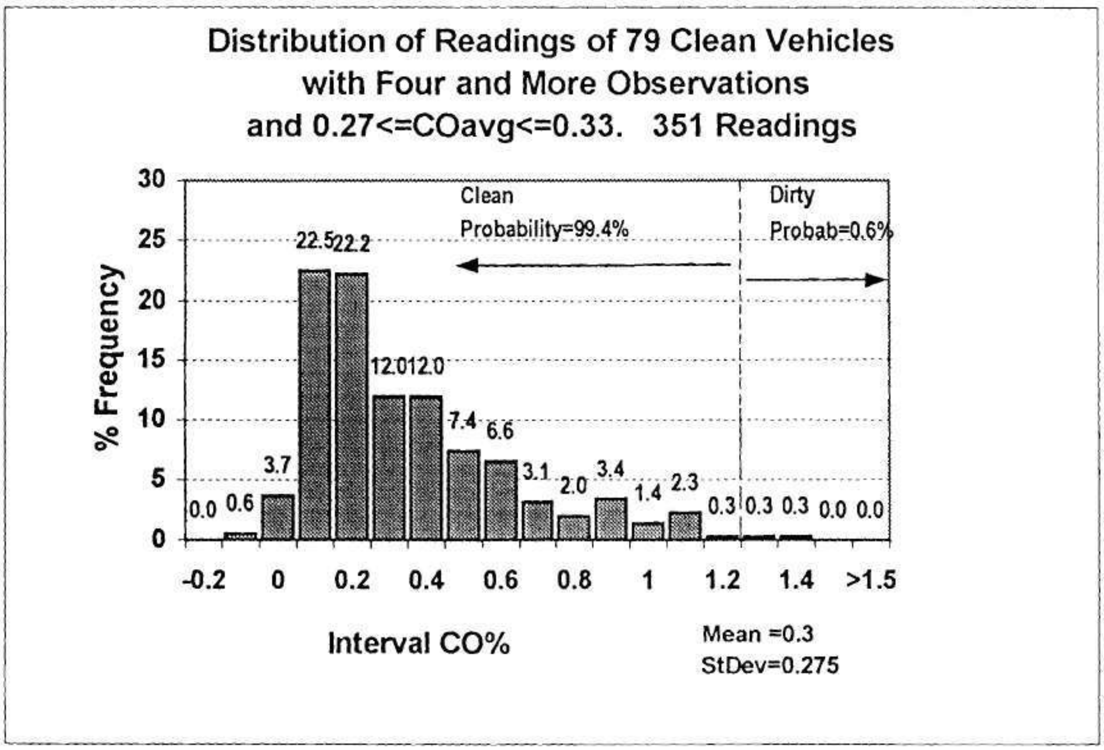


Figure 49 Distribution of Readings of 8 High Emitters 3 and More Observations

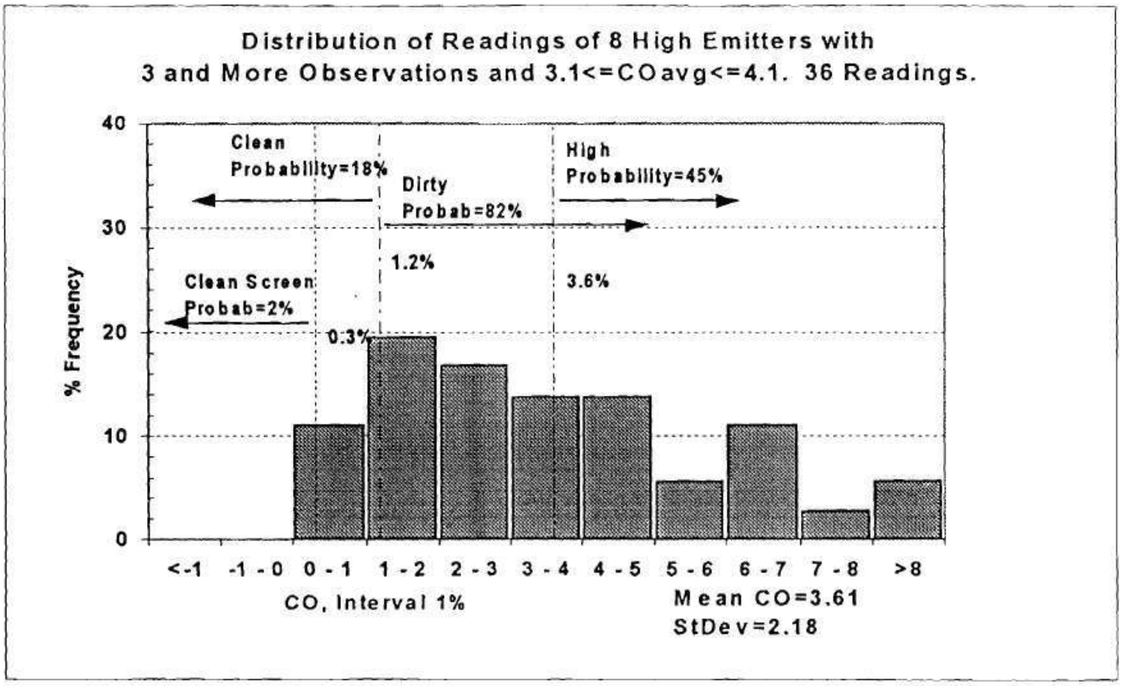


Figure 50 Characteristic Probabilities as Function of Mean CO

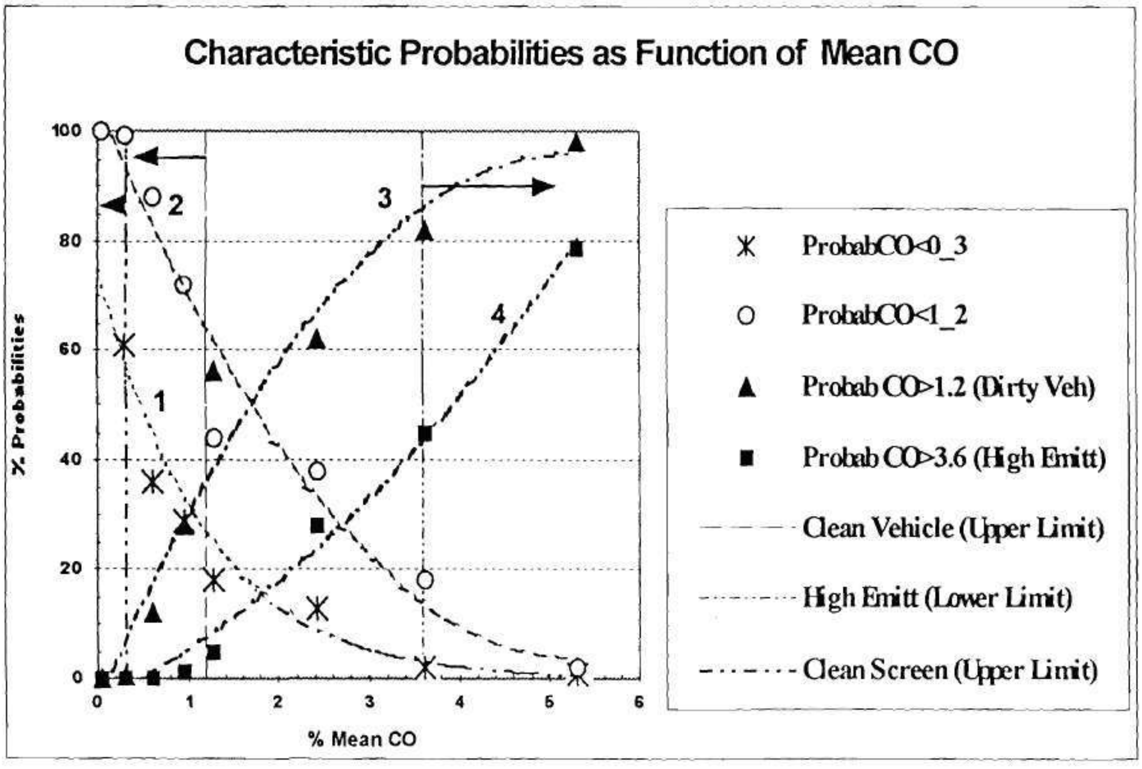


Figure 51 Distribution of Commercial Vehicles CO<=1.2%

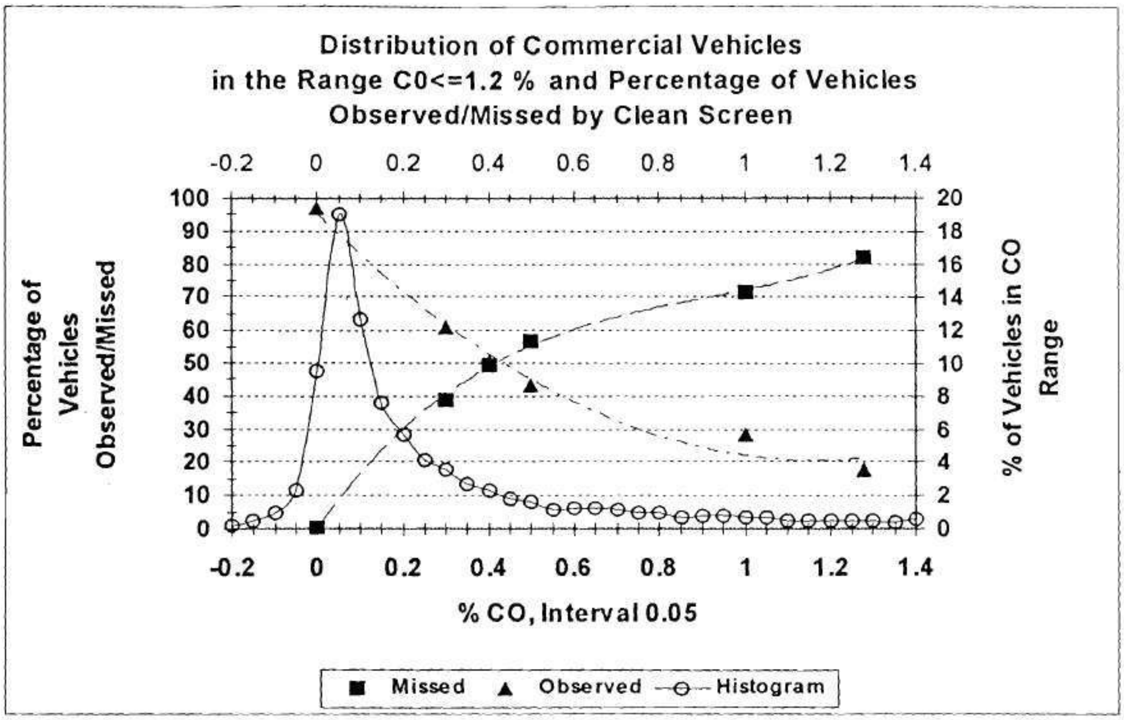


Figure 52 Distribution of Commercial Vehicles CO>=1.2%